MATHEMATICS FOR WATER AND WASTEWATER OPERATIONS

ERRATTA SHEET FOR MATH MANUAL

PAGE NO.	NOW READS	SHOULD READ
43,#5	A 460 m aeration...	A 460 m^3 aeration...
45,#10	is 50 kg BOD/1000 kg MLVSS...	0.5
46,first para	...the CO content...	the CO_2 content...
47,middle	(12.75 m)...	(12.75 m^3)
59,#1	1.56 m /s...	1.56 m^3/s
59,#1	$\dfrac{1.56\ m}{s}$ ...	$\dfrac{1.56\ m^3}{s}$
66,bottom	(1.7 x 1000 m /d)...	(1.7 x 1000 m^3/d)
79,#12	...use m /ha.s ...	...use m^3/ha.s^{-1} ...

ANSWERS TO PROBLEMS

SECTION B

	S.I.	(IMPERIAL)
1.	72 m^2	775 sq. ft.
2.	177 m^2	1901 sq. ft.
3.	144 m^3	5085 cu. ft.
4.	577 m^3	20377 cu ft.
5.	.66 m^3 or 660 L	174 gals.
6.	1.2 L/s, 103.7 m^3/d	27397 gals.
7.	1.5 m^3	396 gals.
8.	25 d, 6 h	
9.	5.7 h or 5 h 42 min	
10.	90 kg	198 Lbs.
11.	0.47 mg/L or 1.3 kg/d	0.47 ppm or 2.81 lbs/d

12.

1 kg	2 kg	4 kg	10 kg	500 g
4 kg	8 kg	16 kg	40 kg	2 kg
20 kg	40 kg	80 kg	200 kg	10 kg
500 g	1 kg	2 kg	5 kg	250 g
200 mg	400 mg	800 mg	2 g	100 mg

13.

1	2	5	20	0.4	
0.2	0.4	1	4	0.08	All Figures
0.1	0.2	0.5	2	0.04	expressed
5	10	25	100	2	mg/L

14.   a) 86.6%   b) 13.4%

15. 540 kg   1191 lbs.

16. 25 kg, 25 L   55 lbs or 6.6 gals

Extra Problems   (IMPERIAL)

1. 4 m^3 141 cu. ft.
2. 3.5 m^3/d   925 gals
3. 630 kg H$_2$O   1389 lbs.
    225 kg C   496 lbs.
    45 kg Al$_2$SO$_4$ 99 lbs
4. 22.5 m^3 or 22 500 L   795 cu. ft. 4961 gals
5. 864 kg   1905 lbs
6. 14.4 mg/L   14.4 ppm
7. 486 L/d sol'n   128 gals

SECTION C

1. 140 m^2 1506 sq. ft.
2. 154 m^2 1646 sq. ft.
3. 48 m^3 12681 gals.
4. 1 021 m^3 269748 gals
5. 1.1 L/s, 95 m^3/d   17 gpm, 25099 gpd
6. 1 800 L or 1.8 m^3/d   475 gals.
7. 25 d
8. 1.56 m^3/s, 1 560 L/s   2469 gpm
9. 6 h (4 fills a day)

10.

1 kg	2 kg	4 kg	10 kg	500 g
4 kg	8 kg	16 kg	40 kg	2 kg
20 kg	40 kg	80 kg	200 kg	10 kg
500 g	1 kg	2 kg	5 kg	250 g
200 mg	400 mg	800 mg	2 g	100 g

11.

1	2	5	20	0.4	
0.2	0.4	1	4	0.08	All figures
0.1	0.2	0.5	2	0.04	expressed
5	10	25	100	2	in mg/L

12. 90 kg Cl$_2$ 198 lbs.

13. 0.7 mg/L, 1.9 kg Cl$_2$/d   0.7 ppm, 4.2 lbs.

EXTRA PROBLEMS

1. 357 m^3 94319 gals.
2. a) 133.3 L/s   2113 gpm
   b) 11 520 m^3/d   3 mgd
3. No; the calculated
   flow is 1 036.8 m^3/d   0.27 mgd
4. 8.4 kg Cl$_2$/d   18.5 lbs.
5. a) 40%
   b) 94%

SECTION E   (IMPERIAL)

1. 3 000 mg/L   3000 ppm
2. 540 kg BOD$_5$ 1190 lbs.
3. 0.5
4. 5 mg O$_2$/h/g
5. 38.34 m^3 8454 gals
6. MLSS 2 364 mg/L
   SVl 88.8
7. SS Concentration 4.8 mg/L
8. 6 810 kg   15013 lbs
9. 2 730 kg   6018 lbs.
10. 3 155 kg   6954 lbs.
11. 3.9 d

SECTION G

1. 0.108
2. 607 kg   1388 lbs.
3. 64% reduction
4. 3.05 kg/m^3/d   0.19 lbs/ft^3/day
5. 1.5 kg/m^3/d   0.09 lbs/ft^3/day
6. 0.6 m^3/kg   9.6 ft^3/lb
7. i) 16 d
   ii) 2.5 kg/m^3/d   0.16 lbs/ft^3/day
   iii) 48.8%
   iv) 0.45 m^3/kg   7.2 ft^3/lb

SECTION I   (IMPERIAL)

1. 46.3 m/h   2.5 ft./min.
2. 10.3 L/m^2.s^{-1}
3. 4 L/m^2.s^{-1}
4. a.) 1.36 L/m^2.s^{-1}
    b.) 4.9 m/h

SECTION K

1. 1.66 mL
2. 1.55 mL
3. 5 425 mL/min or 90.4 mL/s
4. Alum 53 mL/min
    Activated Silica 381.9 mL/min
5. 943 mL/min
    1 357.9 L/d   (359 gals)
6. 162 kg/d   (357 lbs.)

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MATHEMATICS

FOR

WATER and WASTEWATER OPERATIONS

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TABLE OF CONTENTS

INTRODUCTION

OBJECTIVE OF THIS MANUAL

An operator of a water or wastewater treatment plant should routinely evaluate the efficiency of the plant and of the individual units. To do so, with any degree of accuracy, requires that the operator be familiar with basic mathematical concepts.

The objective of this manual is to help the operator to determine process efficiency through the use of mathematical calculations rather than "trial and error" methods. This manual will not dwell on mathematics in general but rather is intended to act as a guide to the operator by providing examples of typical "in-plant" calculations.

Water Treatment Plant Operators are required to perform the following in application of their knowledge to "in-plant" processes.

- manipulation of equations and the utilization of formulae

- area, volume and ratio calculations

- dosage calculations for chlorine and other chemicals used in water treatment

- rate of flow calculations

- detention times

- pumping calculations

- filter loading calculations

- backwash water suspended solids concentrations

- groundwater calculations/well problems

Wastewater Treatment Plant Operators are required to perform the following in the application of their knowledge to "in-plant" processes.

- manipulation of equations and utilization of formulae

- area, volume and ratio calculations

- dosage calculations for chemicals used in wastewater treatment

(i)

- rate of flow calculations

- detention times

- Activated Sludge calculations including:

  - mixed liquor suspended solids determination (MLSS)

  - volatile suspended solids determination (MLVSS)

  - food/microorganism ratio (F/M Ratio)

  - sludge wasting

  - specific uptake rate (SUR)

  - biochemical oxygen demand (BOD)

  - load calculations

- Sludge Digestion calculations including:

  - digester retention time

  - % solids reduction

  - specific gas production

- Pumping calculations

INSTRUCTION FOR THE USE OF THIS MANUAL

This manual is specifically designed to be used in conjunction with the manuals for the Basic Sewage Treatment Operation Course, the Basic Water Treatment Operation Course, the Surface Water Treatment Workshop, the Activated Sludge Process Workshop and the Sludge Digestion and Handling Workshop. It will accompany the training materials sent out to trainees prior to courses.

Prior to attending a course or workshop, the contents of this manual and the course manual must be reviewed by the trainee. The appropriate section(s) detailed below, is (are) to be completed prior to coming on the course and submitted at the time of course registration . The manual will then be graded and problem areas noted. A review will be conducted during the course/workshop to clarify problem areas. The manual will then be returned to the trainees for their own future use.

Section A, example calculations for water and wastewater operators should be read by all trainees prior to attempting any of the working sections in this manual.

a.   Section B - To be completed by those attending the BASIC WATER TREATMENT OPERATION COURSE

b.   Section I & K - To be completed by those attending the SURFACE WATER TREATMENT WORKSHOP

c.   Section C - To be completed by those attending the BASIC SEWAGE TREATMENT OPERATION COURSE

d.   Sections E & K - To be completed by those attending the ACTIVATED SLUDGE PROCESS WORKSHOP

e.   Sections G & K - To be completed by those attending the SLUDGE DIGESTION AND HANDLING WORKSHOP

Complete each question. Space is provided in the working sections for this purpose. If you run out of space, use a piece of foolscap and insert it between the pages of this manual.

Answers to exercises are included at the end of this manual. These should be used to verify your calculations only after completing the exercises.

The answer itself is merely a number that represents a certain value or quantity, and is not important by itself. What is important is the ability of the trainee to understand and use the correct concept(s) in solving routine plant problems. The method of arriving at an answer is the most important aspect of problem solving.

PRACTICAL MATH FOR WATER & WASTEWATER TREATMENT PLANT OPERATORS

In most plants routine laboratory tests are performed to ensure that the plant is effectively tuned to operate under optimum conditions. The analysis of samples, as determined in the laboratory, will assist the operator in deciding whether any adjustments are necessary to the treatment units to achieve the optimum degree of efficiency. The operator must be able to apply the available laboratory data. It is therefore essential that he has a sound knowledge of basic mathematics to help him to fully understand the significance of test results.

The following material contains sample problems indicative of "in-plant" situations as well as a "step-by-step" description of what an operator might consider when solving these. IT IS INTENDED THAT THE OPERATOR WILL TAKE IT UPON HIMSELF TO BECOME FAMILIAR WITH THE MORE FUNDAMENTAL CONCEPTS OF MATHEMATICS!

THE APPROACH

When one sits down to solve a mathematical problem, how should he approach it? Don't write anything until you have read the question thoroughly. Quite often the questions are "word problems", so rather than focus attention on the numbers given or the equations included in a problem, we should first ask ourselves some very basic questions about the mathematical problem itself;

(1) What are you asked to find?

(2) What concept is involved (e.g. volume, area)?

(3) Can you draw a diagram or mentally project what is happening?

(4)   What are you told about the situation you
      are asked to solve?

(5)   Are there any formulae you have come across
      that are applicable to the problem?

(6)   Is there any information not given to you or
      is it hidden somewhere in the question, perhaps
      in another form or with different units that
      need conversion?

Up to this point, you have not used any mathematics. All
you have done is examine the situation depicted in the
problem. This is why you must understand the "in-plant"
processes involved. With mathematics, you can verify that
your observations are correct or given the answer (e.g. from
test results), you can understand what is happening in the
plant.

There are some basic math concepts that, once mastered,
will make your calculations seem simple. The equations quite
often look very complex but once you realize that all they do
is represent words and ideas concerning plant processes, you
will find that they aren't difficult. As a result, you should
make yourself familiar with the operations and processes
involved when dealing with equations. You must be aware of
"units"; they tell you in what terms you are talking (e.g.
metres, litres per second, etc.) and also you will have to
learn how to convert from one unit to another (cm to m, dm^3 to
litres) or from the metric system (kilograms, litres) to the
imperial system (pounds, gallons).

In summary, if you understand completely the processes
taking place in your plant and if you make an effort to learn
the relatively few basic mathematical concepts involved, math
for your in-plant calculations will present no problems.

EXAMPLE CALCULATIONS FOR WATER & WASTEWATER OPERATORS

RATE OF FLOW CALCULATIONS

These calculations are important as they provide data that is necessary in determining the cost of treatment and the efficiency of the process control equipment. The accuracy of the flow metres and pumping capacities can be checked and the measurement of flows, contributed by various sources, such as ground water run-off or industrial wastes, can be estimated with some degree of accuracy. Rates of flow must be determined for proper sizing of clarifiers, aeration tanks, grit chambers, filters etc.

EXAMPLE 1

A channel 2 m wide has a water flowing to a depth of 0.5 m. What is the daily FLOW in the channel if the velocity of the water is 0.75 m/s?
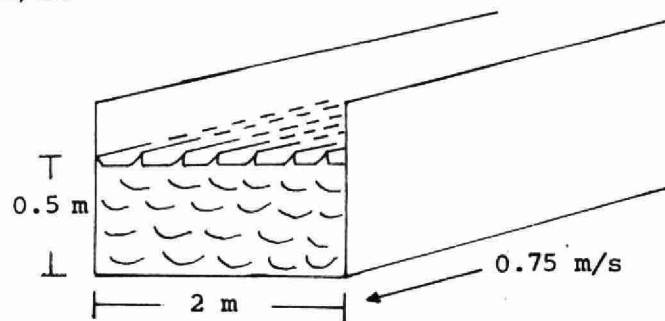
RATE OF FLOW = WIDTH x DEPTH x VELOCITY

= (2 m) (0.5m) (0.75 m/s)

= 0.75 m³/s

However, we are asked to find the daily flow.

Daily Flow = rate of flow x 60 s/min x 1440 min/d

Daily Flow = (0.75 m³/s) (60 s/min) (1440 min/d)

Daily Flow = 64 800 m³/d   (or 14.3 MIGD)

EXAMPLE 2

What is the daily FLOW in a 300 mm diameter pipe that is flowing 75% full if the velocity is 40 m/min?
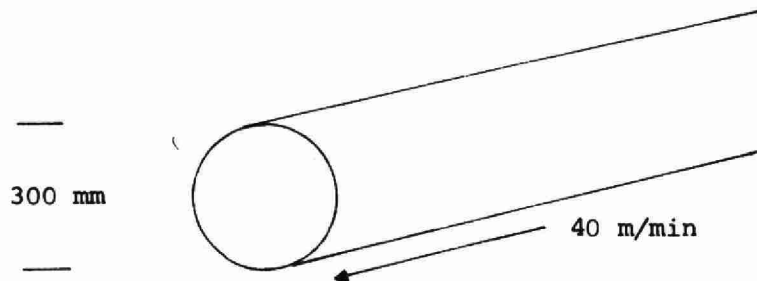
Volume of flow = Cross sectional area x Velocity

$$= (0.75) (\pi r^2) (40 \text{ m/min})$$

$$= (0.75) (3.14) (.15 \text{ m}) (.15\text{m}) (40 \text{ m/min})$$

$$= 2.1 \text{ m}^3/\text{min}$$

We need to convert 2.1 m³/min to a standard expression of flow rate. Either L/s or m³/d are correct, and we are asked to put the answer in terms of daily flow (m³/d).

Daily flow = Volume of Flow x 1440 min/d

$$= (2.1 \text{ m}^3/\text{min}) (1440 \text{ min/d})$$

$$= 3\ 024 \text{ m}^3/\text{d} \qquad (0.7 \quad \text{MIGD})$$

PERCENT

EXAMPLE 1:

A lime solution having a mass of 80 kg contains 85% water and the remainder is lime. What is the mass of the lime?

SOLUTION

The total mass of the solution is 80 kg which represents 100%.

If the water represents 85%, then the lime represents:

    100%   −   85%   =   15%

(Total Mass) − (Mass of Water) = (Mass of Lime)

Mass of lime = 15% x 80 kg

               = 0.15 x 80 kg = 12 kg

EXAMPLE 2:

An alum solution having a mass of 200 kg contains 176 kg of water and the rest is alum.

a)   What percentage of the mixture is water?

b)   What percentage of the mixture is Alum?

<u>SOLUTION</u>

a) In the above question we are told the total mass of
    the mixture is 200 kg or 100%. The mass of the
    water is 176 kg.

    To find the percentage of water:

$$\% \text{ of water} = \frac{176 \text{ kg}}{200 \text{ kg}} \times 100\%$$

$$88\% \text{ of water} = \frac{176 \text{ kg}}{200 \text{ kg}} \times 100\%$$

b) Obviously if 88% of the mixture is water then

Total Mass - Mass of Water = Mass of Alum

   100%   -   88%   =   12%

<u>DETENTION TIME</u>

The concept of detention time is used in conjunction with
many treatment plant processes. "DETENTION TIME' refers to
the length of time a drop of water or a suspended particle
remains in a tank or chamber.

Detention time may also be thought of as the number of
minutes or hours required for each tank emptying. The mental
image might be one of the flow from the time water enters the
tank until it leaves the tank completely ("plug flow"), as
shown in the following figure.

| At Start | After 5 minutes (Halfway through chamber) | After 10 minutes (Completely through chamber) |

TEN MINUTES DETENTION TIME

4
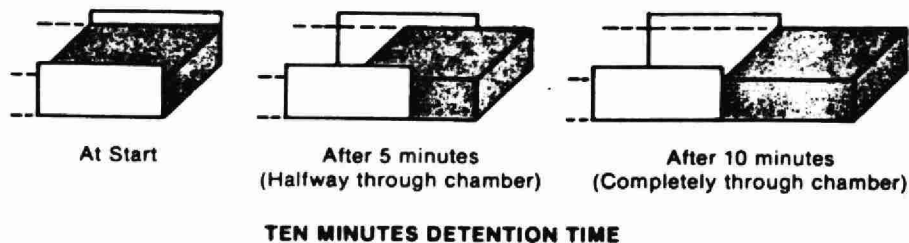
EXAMPLE

A sedimentation tank has a capacity of 132 m³. If the
hourly flow to the clarifier is 47 m³/h, what is the
detention time?

Since the flow rate is expressed in hours, the deten-
tion time calculated is also in hours:

Detention time = $\dfrac{\text{Volume of tank}}{\text{Flow rate}}$

$= \dfrac{132 \text{ m}^3}{47 \text{ m}^3/\text{h}}$

$= 2.8 \text{ h}$

WEIR OVERFLOW RATE

The calculation of WEIR OVERFLOW RATE is important in
detecting high velocities near the weir, which adversely
affect the efficiency of the sedimentation process. With
excessively high velocities, the settling solids are pulled
over the weirs and into the effluent troughs.

In calculating the weir overflow rate, you will be
concerned with the litres per second flowing over each metre
of weir length. The following figures can be associated with
weir overflow rate in rectangular and circular sedimentation
basins.
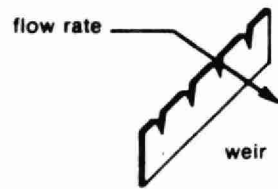
WEIR OVERFLOW RATE
Rectangular Clarifier
(Sedimentation Tank)
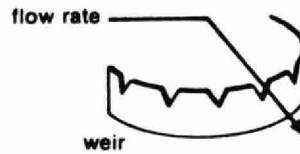
WEIR OVERFLOW RATE
Circular Clarifier

Since weir overflow rate is L/s flow over each m of weir length, the corresponding mathematical equation is;

$$\text{Weir overflow rate} = \frac{\text{flow (L/s)}}{\text{weir length (m)}}$$

EXAMPLE 1

If a sedimentation tank has a total of 27 m of weir over which the water flows, what is the weir overflow rate when the flow is 90 L/s?

90 L/s **flow rate**

weir 27 m
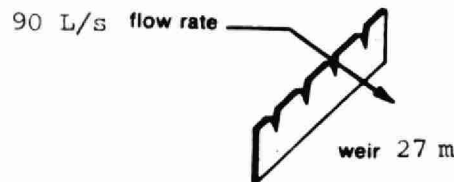
$$\text{Weir overflow rate} = \frac{\text{flow (L/s)}}{\text{weir length (m)}}$$

$$= \frac{90 \text{ L/s}}{27 \text{ m}}$$

$$= \frac{3.3 \text{ L/s}}{\text{m}}$$

6

EXAMPLE 2

A circular clarifier receives a flow of 16 416 m³/d.
If the diameter is 24 m, what is the weir overflow
rate?

16 416 m³/d flow rate

24 m weir
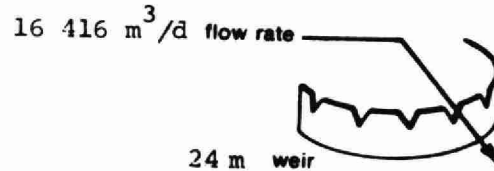
Before you can calculate the weir overflow rate, you
must know the total length of the weir. The relation-
ship of the diameter and circumference of a circle
is the key to determining this.

Circumference = 3.14 x Diameter

In this problem, the diameter is 24 m. Therefore, the
length of weir (circumference) is

Circumference = (π) (Diameter)

= (3.14) (24 m)

= 75.4 m

We now must convert m³/d to L/s by the following:

$$\frac{m^3/d}{s/d} \quad x \quad \frac{1\ 000\ L}{m^3} \quad = \quad L/s$$

$$\frac{16\ 416\ m^3/d}{86\ 400\ s/d} \quad x \quad \frac{1\ 000\ L}{m^3} \quad = \quad 190\ L/s$$

7

Now solve for the weir overflow rate:

$$\text{Weir overflow rate} = \frac{\text{flow (L/s)}}{\text{weir length (m)}}$$

$$= \frac{190 \text{ L/s}}{75.4 \text{ m}}$$

$$= \frac{2.5 \text{ L/s}}{\text{m}}$$

PUMPING RATES

The rate of flow produced by a pump is expressed as the volume of water pumped during a given period of time. The mathematical equation used in pumping rate problems can usually be determined from the verbal statement of the problem.

VERBAL: What is the pumping rate in m^3 per day?

     MATH: pumping rate = $\dfrac{m^3}{d}$

VERBAL: What is the pumping rate in litres per second?

     MATH: pumping rate = $\dfrac{L}{s}$

The volume pumped during a period can be determined either by a flow meter or by measuring the volume pumping into or out of a tank.

Most pumping rate problems will ask you to give an answer in one form (L/s) and will give you the information in another form (m^3/d). At first the conversion between these two expressions looks difficult, but once you become familiar with their relationship to each other, converting is simple. Here is the proof.

$$\frac{m^3/d}{86\ 400 \text{ s/d}} = \frac{m^3}{s} \times \frac{1\ 000 \text{ L}}{m^3} = \frac{L}{s} \quad \text{or L/s}$$

or conversely

$$\frac{L}{s} \div \frac{1\ 000 \text{ L}}{m^3} = \frac{m^3}{s} \times \frac{86\ 400 \text{ s}}{d} = \frac{m^3}{d} \quad \text{or } m^3/d$$

EXAMPLE

An empty rectangular tank 8 m long and 6 m wide can hold water to a depth of 2 m. If this tank is filled by a pump in 55 min. What is the pumping rate in litres per second?

In this example, the entire tank was filled during the 55 min pumping test. Therefore the total volume pumped is equal to the capacity of the tank in m^3.

Volume of Tank = Area of Rectangle x Depth

$$= (8 \text{ m}) (6 \text{ m}) (2 \text{ m})$$

$$= 96 \text{ m}^3$$

To find L/s we convert 96 m^3 to litres and 55 min to seconds.

$$96 \text{ m}^3 \text{ x } \frac{1\ 000 \text{ L}}{m^3} = 96\ 000 \text{ L}$$

$$55 \text{ min x } \frac{60 \text{ s}}{min} = 3\ 300 \text{ s}$$

Then we divide:

$$\frac{96\ 000 \text{ L}}{3\ 300 \text{ s}} = 29.1 \text{ L/s}$$

29.1 L/s is the answer to the first part of the question.

To find the answer to the second part, we must covert L/s to m^3/d.

$$\frac{29.1 \text{ L}}{s} \div \frac{1\ 000 \text{ L}}{m^3} \text{ x } \frac{86\ 400 \text{ s}}{d} = 2\ 514 \text{ m}^3/\text{d} \ (0.55 \text{ MIGD})$$

2 514 m^3/d is the answer to the second part of the question.

DENSITY

For scientific and technical purposes, the DENSITY of a body of material is precisely defined as the mass PER UNIT OF VOLUME. The density of dry materials, such as sand, activated carbon, lime and liquids such as water, liquid alum or liquid chlorine can be expressed as g/cm^3. The density of gases, such as air, chlorine gas, methane or carbon dioxide is normally expressed in g/L.

The density of a substance CHANGES SLIGHTLY AS THE TEMPERATURE OF THE SUBSTANCE CHANGES. This happens because substances usually increase in volume as they become warmer, as illustrated in Figure 1. Because of the expansion with warming, the mass is spread over a larger volume, so the density is less when a substance is warm than when it is cold.

Similarly, a change in pressure will change the volume occupied by a substance. As a result, DENSITY VARIES WITH PRESSSURE, increasing as pressure increases and decreasing as pressure decreases (Figure 2).

The effects of pressure and temperature on solids and liquids, are very small and are usually ignored. However, temperature and pressure have a significant effect on the density of gases and whenever the density of a gas is given, then the temperature and pressure at that density are usually also given.
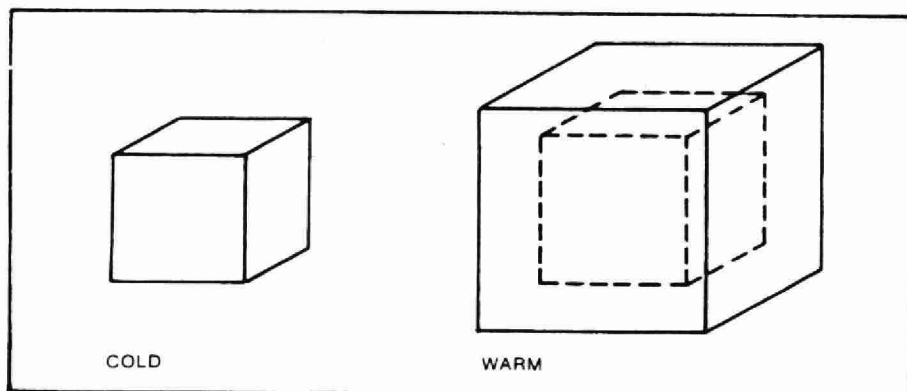
Figure 1.   Density Changes as Temperature Changes
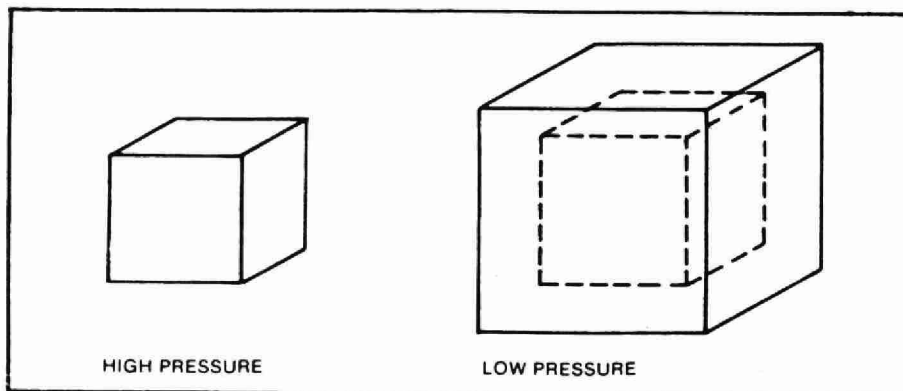
Figure 2.   Density Changes as Pressure Changes

RELATIVE DENSITY (Specific Gravity)

Although there may be many numbers that express the density of the same substance (depending on the unit used) there is only one relative density associated with each substance (for one particular temperature and pressure). The relative density of a substance is compared against a "Standard" density.

RELATIVE DENSITY OF SOLIDS & LIQUIDS

The standard density used for solids and liquids is that of water, which is one g/cm^3 at 4 degrees °C and a pressure of 101.3 kN/m or kilopascals (kPa), the pressure of the atmosphere at sea level. Therefore, the relative density of a solid or liquid is the density of that solid or liquid COMPARED TO THE DENSITY OF WATER. It is the ratio of the density of that substance to the density of water.

Let's look at an example. The density of SAE 30 motor oil is

$$\text{Relative Density} = \frac{\text{oil}}{\text{water}} \quad \frac{0.9 \ g/cm^3}{1.0 \ g/cm^3}$$

$$= 0.90$$

In other words, relative density in this example tells you that oil is only 9/10 as dense as water. Because a cm^3 of oil has a mass less than cm^3 of water, oil floats on the surface of water.

Relative Density of Gases

The relative density of a gas is usually determined by comparing the density of the gas with the density of air, which is 1.2 g/L at a temperature of 20 degrees °C and a pressure of 101.3 kN/m or kilopascals (kPa) the pressure of the atmosphere at sea level. For example, the density of chlorine gas is 2.99 g/L . Its relative density would be calculated as follows:

$$\text{Relative Density} = \frac{\text{Cl}}{\text{air}} \quad \frac{2.99 \ g/L}{1.2 \ g/L}$$

$$= 2.49$$

This tells you that chlorine gas is approximately 2.5 times as dense as air. Therefore, when chlorine gas is introduced into a room it will concentrate at the bottom of the room. This is important to know since chlorine is a deadly poisonous gas.

DOSAGE CALCULATIONS

It is very necessary for a plant operator to know how to calculate the dosages of the various chemicals used in water and wastewater treatment. It is important to be accurate when calculating dosages as too little chemical may be ineffective and too great a dosage, a waste of money. As a result, for process control the exact dose of chemical to be added must be determined for the purposes of efficient operation and economy.

EXAMPLE 1:

The chlorine dosage of an effluent is 15 mg/L. How many kilograms of chlorine will be required to dose a flow of 8 500 m³/d.

In this question, it will be necessary to utilize our knowledge of the metric system.

1 mg/L = 1 kg/1 000 m³

for every 1 000 m³ of water   flow, we will
need to use 15 kg chlorine

$$\frac{15 \text{ kg Cl}_2}{1 \text{ 000 m}^3} \times 8 \text{ 500 m}^3/d = 127.5 \text{ kg Cl}_2/d \text{ (281 lbs Cl}_2/d)$$

Above we expressed 15 mg/L as 15 kg Cl₂/1 000 m³ and multiplied it by the flow to obtain the answer expressed as 127.5 kg Cl₂/d.

EXAMPLE 2:

A chlorinator is set to feed a 94.8 kg/d of chlorine. If the average daily flow through the plant is 7 900 m³/d, what is the DAILY AVERAGE CHLORINE DOSAGE IN MG/L?

We know that 1 mg/L = $\frac{1 \text{ kg}}{1 \text{ 000 m}^3}$

We are told we use 94.8 kg chlorine for every 7 900 m³ water.

$$\frac{94.8 \text{ kg } Cl_2/d}{7.9 \times 1\,000 \text{ m}^3/d} \quad = \quad \frac{12 \text{ kg } Cl_2}{1\,000 \text{ m}3} \quad = \quad 12 \text{ mg/L}$$

Above we divided the mass of chlorine used per day by the flow expressed in 1 000 m³ per day and found we used 12 kg Cl_2 every 1 000 m³ of flow or 12 mg/L.

HYPOCHLORINATION CALCULATIONS

Definition - Hypochlorination is the application of hypochlorite (a compound of chlorine and another chemical), usually in the form of solution, for disinfection purposes.

Example 1:

The secondary effluent at a treatment plant requires a chlorine dosage of 98 kg/d for disinfection purposes. If we are using a solution of hypochlorite containing 60% available chlorine, how many kg/d hypochlorite will be required?

SOLUTION:

We are told in the problem that 60% of the hypochlorite is available chlorine which is the portion of the solution capable of disinfecting.

Solving the equation we have:-

kg/d hypochlorite = $\dfrac{98 \text{ kg/d of chlorine needed}}{0.6 \text{ available chlorine in sol'n}}$

= 163.3 kg/d hypochlorite solution

EXAMPLE 2:

A hypochlorite solution contains 5% available chlorine. If 4 kg of available chlorine are needed to disinfect a watermain, how much 5% solution would be required?

We are told 4 kg of chlorine will do the job of disinfection. By a 5% solution we mean that 5% by mass of the solution is to be made up of chlorine. So 100 kg of 5% hypochlorite solution will contain 5 kg chlorine.

13

or   100 kg 5% solution contains 5 kg chlorine

      20 kg 5% solution contains 1 kg chlorine

      4 kg chlorine diluted to 5% will cause the solution
      to have a mass of 4 x 20 kg = 80 kg hypochlorite
      solution.

CHEMICAL FEEDING

Solution Preparation - Jar Tests

Jar tests are used to determine correct chemical dosages
for such chemicals as alum, ferric chloride, activated silica.
These are chemicals utilized in water treatment facilities for
coagulation and flocculation of colloidal particles and are
used in wastewater treatment facilities for chemical
precipitation of phosphorous. The jar test simulates, on a
small scale, the activities going on in various sections of
the full scale treatment process. Varying amounts of the
above mentioned chemicals are compared to see which chemical
and dosage best accomplishes coagulation and flocculation in
water treatment and the chemical precipitation of phosphorous
in sewage treatment.

Stock solutions of coagulants, coagulant aids and other
chemicals, should be prepared at concentrations such that
quantities suitable for use in the jar tests can be measured
accurately and conveniently. If one is dealing with dry
chemicals the preparation of these stock solutions is quite
straight forward. For example to prepare a 1 g/L stock
solution using dry chemicals, 1 gram of the chemical is made
up to 1 000 mL with water. However, with concentrated liquid
solutions a dilution step needs to be done. Any dilution step
must take into account the <u>relative density</u> of the solution
being diluted. For example, if one has a 48.5% alum solution
with a relative density of 1.35 and wishes to make up a 1 g/L
          procedure should be followed:

      1 mL 48.5% liquid alum has a mass of 1.35 g

      1 mL contains 1.35 g x $\frac{48.5}{100}$ = 0.65 g alum

      mL containing 1 g Alum = $\frac{1}{.65}$ = 1.54 mL

Therefore, add 1.54 mL liquid alum to water and make up to 1
000 mL for a 1 g/L stock solution. 1 g/L solutions are easy
to use because 1 mL of solutions has a mass of 1 mg.

CHEMICAL FEEDING

After jar tests have been carried out the type of chemical dosage and point of application best suited to the characteristics of the water or sewage to be treated should easily be established. The next step is to feed the chemical to be used at the dosage determined in the jar tests into the full scale treatment facility. The operator will be faced with using a dry chemical or a liquid chemical which will be fed into the process by means of a dry chemical feeder or a liquid chemical feeder. If feeding dry chemicals, the feeder will be calibrated, most likely, in grams per minute or, if liquid chemicals are being utilized, in millilitres per minute. Following is a detailed approach to establishing feed rates for chemicals.

Example

Given a daily flow rate of 16 000 m^3/d and Fe+3 dosage of 13 mg/L, what is the ferric chloride ($FeCl_3$) flow rate in mL/min?

Ferric Chloride   1.39 kg/L

Fe+3   13.7% by mass in the solution

Step 1   Determine kg/d of Fe+3 required.

1. Fe+3   dosage of 13 mg/L = $\dfrac{13 \text{ kg}}{1\ 000 \text{ m}^3}$

2. Dosage in kg/d = Dosage in kg/1 000 m^3 x flow in m^3/d.

$$= \frac{13 \text{ kg}}{1\ 000 \text{ m}^3} \ \text{x} \ \frac{16\ 000 \text{ m}^3}{d}$$

$$= 208 \text{ kg/d Fe+3}$$

Step 2   Determine kg/d of solution

Fe is 13.7% by mass of solution

Amount of solution required = $\dfrac{208 \text{ kg/d}}{0.137}$

= 1 518.2 kg/d

Step 3   We are asked to give the flow rate in mL/min

1. Convert kg/d to L/d

Since 1 L has a relative density of 1.39 kg/L

$\dfrac{1\ 518.2 \text{ kg}}{d} \div \dfrac{1.39 \text{ kg}}{L} = \dfrac{1\ 092.2 \text{ L}}{d}$

2. Convert $\dfrac{L}{d}$ to mL/min

Since 1 L is equivalent to 1 000 mL

$\dfrac{1\ 092.2 \times 1\ 000 \text{ mL/L}}{1\ 440 \text{ min/d}} = 758.5 \text{ mL/min}$

16

SECTION B

Basic Math - Water Treatment Operations

1. Calculate the <u>surface area</u> of a rectangular settling tank 18 m long <u>and 4 m wide</u>.

2. Calculate the <u>surface area</u> of a circular sand filter that has a diameter of <u>15 m</u>.

3. Calculate the volume of a raw water intake crib that is 8 m long, 3 m wide and 6 m deep.

4.   What is the _volume_ of a cylindrical storage tank
       that is 7 m in diameter and 15 m high?

5.   What is the _volume_ contained by 84 m of
       a 10 cm pipe?

       a) in m^3

       b) in L

6.   If a pump delivers 1.44 m^3 in 20 minutes, what is
       the _pumping rate_ in,

       a) L/s?

       b) m^3/d?

7.   How many m³ of water will a 5 L/s pump deliver
      in 5 minutes?

8.   A 12 m³ storage tank suppies alum for
      coagulation at a rate of 330 mL/min.
      How often will the tank need refilling?

9.   The prechlorination chamber at a water treatment
      plant has a volume of 225 m³. If the flow rate out
      of the tank is 11 L/s, what is the average detention
      time in hours?

10.   How many kg of chlorine are required each day to
       treat 18 000 m³ with chlorine at 5.0 mg/L?

11.   A gas chlorinator treats 2 700 m³ with 2 kg of
       chlorine each day. Calculate the dosage rate.
       The residual is measured at 0.27 mg/L. What is
       the chlorine demand ?

       a)   in mg/L

       b)   in kg/d

12.   In the chart below you are required to determine the
       mass of chemical in kg that will be required to dose
       at the rate indicated along the top of the chart in
       relationship to the volume of water flowing in which
       is indicated along the side.

Volume of water ╲ dosage rate	1.0 mg/l	2.0 mg/l	4.0 mg/l	10 mg/l	0.5 mg/l
1,000 m³					
4,000 m³					
20,000 m³					
500 m³					
200 L					

13. In the chart below you are required to determine the
    <u>dosage</u> in mg/L that coincides with the flow indicated
    on the vertical scale and the mass of alum indicated
    on the horizontal scale.

Volume of water \ Mass of alum	1.0 kg	2.0 kg	5.0 kg	20 kg	0.4 kg
1,000 m^3					
5,000 m^3					
10,000 m^3					
200 m^3					

14. A liquid mixture with a total mass of 97 kg
    contains 84 kg of water and the remainder
    is alum.

    a) Calculate the percent that is water.

    b) Calculate in percent the fraction that is alum.

15. A solution of water and powdered carbon is to be 85%
    water. If the total volume of solution required is
    3.6 m^3, what is the mass of the powdered carbon?

16. A hypochlorite solution contains 12% available
     chlorine. If 3 kg of available chlorine are needed
     to disinfect a main.

     a) How many kg of solution are required?

     b) How many litres of solution are required?

BASIC WATER TREATMENT MATH
(EXTRA PRACTICE CALCULATIONS)

1. Calculate the volume contained by 30 m of pipe that is 412 mm in diameter.

2. A rectangular storage tank for an alum solution that is 7 m long, 5 m wide and 3 m deep after filling takes 30 days to empty. What is the rate at which the alum solution is being used up? (Express the answer in m^3/d).

3. A solution is composed of three substances: water, powdered carbon and alum and the total mass is 900 kg. Calculate the mass of each substance if it is known that 70% is water and 25% is carbon.

4. A water treatment plant has a flow of 2 700 m^3/d. If the average detention time in the chlorine contact chamber is to be 12 minutes, what should the volume of the chamber be?

5. A 0.0005% concentration of copper sulphate is used for controlling algae in a reservoir. The volume of the reservoir is 172 800 m^3. What is the mass of copper sulphate required?

6. A well produces 1 800 m^3 of water and is chlorinated by using 26 kg of chlorine each day. Calculate the dosage?

7. An operator chlorinates a well water supply, using a hypochlorinator. The well pump rate is 450 L/s the hypochlorite solution is 20% available chlorine and the dosage is 2.5 mg/L. How many litres of hypochlorite solution are used daily?

SECTION C

Basic Math - Wastewater Operations

1.   What is the surface area of a rectangular clarifier 7 m wide and 20 m long?

2.   What is the surface area of a circular clarifier 14 m in diameter?

3.   What is the volume of a chlorine contact chamber 8 m long, 3 m and 2 m deep?

24

4.   What is the volume of a cylindrical storage tank
       that is 10 m in diameter and 13 m high?

5.   If a pump delivers 1.32 m^3 in 20 minutes, what is
       the pumping rate in

       a)   L/s?

       b)   m^3/d?

6.   A 6 L/s pump operates for 5 minutes. How much
       water is pumped?

7.   A 12.3 m^3 alum storage tank supplies alum for
      phosphorous removal treatment at a rate of
      342 mL/min. How often will the tank need
      refilling?

8.   Sewage flows through a rectangular channel 1 m wide
      and 60 cm deep at a rate of 2.6 m/s. What is the flow
      rate in

      a)   m^3/s?

      b)   L/s?

9.   The aeration section of a 900 m^3/d plant has a volume
      of 225 m^3. What is the average detention time of the
      aeration section?

10.   In the chart below you are required to determine the
       mass of chemical that will be required to dose at the
       rate indicated along the top of the chart in relation-
       ship to the volume of water flowing; which is
       indicated along the side.

dosage rate Volume of water	1.0 mg/l	2.0 mg/l	4.0 mg/l	10 mg/L	0.5 mg/L
1,000 m^3					
4,000 m^3					
20,000 m^3					
500 m^3					
200 L					

11.   In the chart below you are required to determine the
       dosage in mg/L that coincides with the flow indicated
       on the vertical scale and the mass of ferric chloride
       indicated on the horizontal scale.

Mass of $FeCl_3$ Volume of water	1.0 kg	2.0 kg	5.0 kg	20kg	0.4kg
1,000 m^3					
5,000 m^3					
10,000 m^3					
200 m^3					

12.   What mass of chlorine is required daily to dose the
      effluent of an 18 000 m^3/d plant at 5.0 mg/L?

13.   A gas chlorinator is set to dose an effluent of
      2 700 m^3/d with 10 kg of chlorine each day. If the
      chlorine demand is 3.0 mg/L calculate the chlorine
      residual in

      a)   mg/L

      b)   kg/d

BASIC WASTEWATER TREATMENT OPERATION
(EXTRA PRACTICE CALCULATIONS)

1. An aerator tank is 3 m deep, 7 m wide and 17 m long. Calculate its volume?

2. A 2 400 m^3 tank has a detention time of 5 hours. Calculate the flow in

   a) L/s

   b) m^3/d

3. The venturi meter at a plant records a fairly constant flow of 1 000 m^3/d while at the same time the operator observes that the flow in the channel (0.6 m wide and 0.2 m deep) is about 0.1 m/s. Is the meter recording accurately?

4. If the chlorine dose rate at a 1 400 m^3/d plant is 6.0 mg/L. How much chlorine is consumed daily?

5. Raw sewage entering the primary clarifier has a suspended solids content of 250 mg/L. The concentration is reduced to 150 mg/L in the primary effluent and 15 mg/L in the final effluent. Calculate the solids removal efficiency (in percent) of the:

   a) primary section

   b) the whole plant

SECTION D

EXAMPLE CALCULATIONS FOR ACTIVATED SLUDGE

MIXED LIQUOR SUSPENDED SOLIDS DETERMINATION (MLSS)

MLSS is usually reported in mg/L, and is determined using the formula,

$$MLSS = \frac{(B-A)\ (1\ 000\ mg/g)\ (1\ 000\ mL/L)}{V}$$

Where

B = Dried mass of filter paper and solids in grams

A = Dried filter paper mass (mass in grams)

V = Volume of sample used in mL (aliquot)

1 000 mg/g converts mass in grams to mass in milligrams

1 000 mL/L coverts volume from mL to litres

EXAMPLE

Given

Sample volume of mixed liquor used   = 50 mL   (V)

Dried filter paper mass (Tare)   = 0.215 7 g   (A)

Dried mass of filter paper + solids   = 0.437 6 g   (B)

Determine the MLSS in mg/L

SOLUTION

$$MLSS = \frac{(0.437\ 6\ g - 0.215\ 7\ g)\ (1\ 000\ mg/g)\ (1\ 000\ mL/L)}{50\ mL}$$

$$= \frac{(0.221\ 9\ g)\ (1\ 000\ mg/g)\ (1\ 000\ mL/L)}{50\ mL}$$

$$= 4438\ mg/L$$

F/M RATIO

F/M RATIO (FOOD/MICROORGANISM RATIO) is the relationship between the mass of food (measured by BOD_5 of the aerator influent) and the mass of the microorganisms in the aerator (as measured by the MLVSS).

$$\frac{F}{M} = \frac{BOD_5 \; kg}{MLVSS \quad kg}$$

When operating an activated sludge plant the process must be maintained within the recommended F/M ranges by controlling the aeration MLVSS concentration. Otherwise aeration mixed liquor flocculation will be disrupted or filamentous organisms may develop causing poor sedimentation. To correct an F/M ratio outside of the recommended range, the operator must change the wasting rate to effect a change in MLVSS.

EXAMPLE 1:

A conventional activated sludge treatment receives a daily flow of 20 250 m³/d with a primary effluent BOD_5 of 165 mg/L. If 6 750 kg of MLVSS are maintained in the aerator, what is the F/M ratio?

SOLUTION:

BEFORE determining the F/M loading ratio, we must calculate the mass of BOD_5 entering the aerator daily. Therefore, we must convert mg/L BOD to kg of BOD daily.

(165 mg/L) (20 250 m³/d) = 3341.25 kg BOD/d

$$F/M = \frac{kg \; BOD_5 \; daily}{kg \; MLVSS \; in \; aerator} = \frac{3 \; 341.25 \; kg \; BOD/d}{6 \; 750 \; kg \; MLVSS}$$

= 0.495

SOLIDS RETENTION TIME (S.R.T.)

The length of time that biological solids are held within the process is known as the Solids Retention Time (SRT). This factor is stated in days and is calculated as follows:

$$S.R.T. \text{ (d)} = \frac{\text{mass of aeration MLSS (kg)}}{\text{mass of wasted solids (kg/day) + mass of solids in effluent (kg/day)}}$$

Just as with the F/M ratio, S.R.T. can be used to design or maintain an Activated Sludge process for a given treatment proficiency.

For BOD_5 removal, conventional and contact stabilization plants should be designed and operated in an S.R.T. range of 2 to 5 days with the upper limit used for winter operation. If nitrification is also required year-round, then process S.R.T's over 5 days must be utilized. Like F/M, S.R.T. values are adjusted by varying the amount of solids wasted daily.

EXAMPLE

Given:

Suspended Solids Concentration in effluent = 15 mg/L

Aeration tank volume = 1 560 m^3

MLSS = 2 850 mg/L

FLOW = 11 400 m^3/d

Daily waste volume = 100 m^3

Waste A.S. Suspended Solids = 9 300 mg/L

Find the S.R.T.

SOLUTION

A. Mass of Aeration MLSS in aeration tank

2 850 mg/L = 2 850 mg x 1 560 m^3/d

= 4 446 kg MLSS   (9 801 lbs)

32

B. mass of wasted solids   (kg/d)

9 300 mg/L = (9 300 mg/L) (100 m³/d)

= 930 kg/d   (3 050 lbs)

C. kg of solids lost in effluent $\left(\text{kg/d}\right)$

15 mg/L = (15 mg/L) (11 400 m³/d)

= 171 kg/d

D. S.R.T. = $\dfrac{4\ 446\ \text{kg}}{930\ \text{kg/d} + 171\ \text{kg/d}}$

= 4.04 d

If the operator wished to increase this to 5 days he would have to reduce the amount of daily waste.

SLUDGE WASTING:

In order to attain an equilibrium in the food to microorganisms ratio, it will be necessary to "waste" some activated sludge. Continuous wasting that is proportional to the degree of organic loading in the incoming flow <u>or</u> batch wasting, at times of low hydraulic loads, are two ways in which this process may be achieved. the amount of sludge to be wasted can be determined if the <u>suspended solids in the aeration tank and sludge return are measured</u> . The excess solids are determined by comparing the desired solids in the system with the existing solids.

EXAMPLE

Given a sludge return concentration of 9 800 mg/L suspended solids, an MLSS of 5 300 mg/L, and the aeration tank capacity of 1 250 m³ , calculate:

a) What volume of sludge must be diverted to waste in order to reduce the MLSS to 4 200 mg/L?

b) What would be the pumping rate (L/s)

i) if wasted continuously over a 24-hour period?

ii) if batch wasted over a 6-hour period?

<u>SOLUTION:</u>

Formula

$$X = \frac{(M_1 - M_2)\ V}{R}$$

Where　M_1 = 　MLSS (mg/L)

　　　　M_2 = 　Required MLSS (mg/L)

　　　　V　 = 　Volume aeration tank (m)

　　　　R　 = 　suspended solids in sludge return (mg/L)

　　　　X　 = 　m　to waste

a)　The solution of the above problem requires only substitution of given values into the formula.

$$X = \frac{(5\ 300\ \text{mg/L} - 4\ 200\ \text{mg/L})\ (1\ 250\ \text{m}^3)}{9\ 800\ \text{mg/L}}$$

$$= \frac{(1\ 100\ \text{mg/L})\ (1\ 250\ \text{m}^3)}{9\ 800\ \text{mg/L}}$$

$$= 140.3\ \text{m}^3 \qquad (30\ 767\ \text{gals})$$

b)　(i)　Amount of sludge to be wasted = 　140.3 m^3
　　　　Time period of wasting 　　　 = 　24 hrs

$$\text{Pumping Rate} = \frac{140.3\ \text{m}^3}{86\ 400\ \text{s/d}} = 28.38\ \text{m /h or 6.495 L/s}$$

<u>CLARIFIER UPFLOW RATE</u>

　　　The amount of wastewater flowing into a clarifier relative to the surface area of the clarifier is known to affect the settleable solids and BOD removal efficiency during sedimentation.

　　　A means of determining this "surface loading rate" is to compare the volume of flow of wastewater entering the clarifier to the surface area of the clarifier. The units of measurement are therefore volume of wastewater daily per square metre of clarifier surface area or,

$$\frac{\text{average daily flow } /1\ 000\ \text{m}^3/\text{d}}{\text{surface area of final clarifier (m}^2)}$$

34

<u>EXAMPLE:</u>

The flow to a treatment plant is 9 100 m³/d. If there are two final clarifiers, each with a diamater of 14 m calculate the clarifier upflow rate.

<u>SOLUTION:</u>
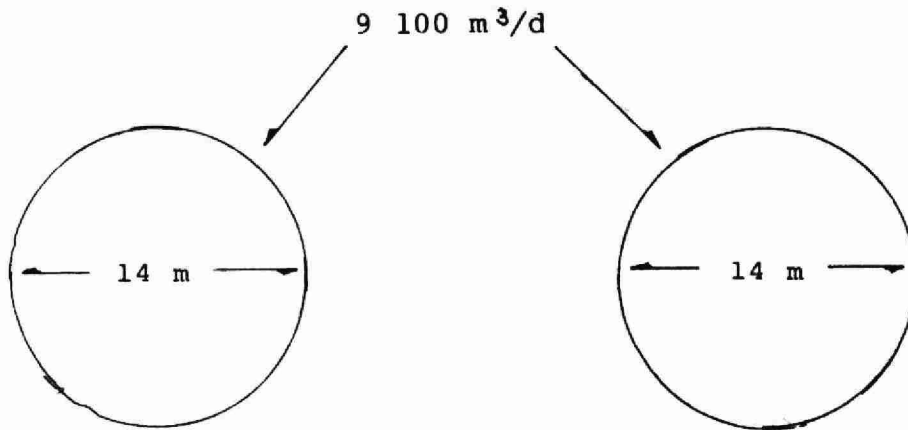
9 100 m³/d

Final Clarifiers

Referring to the above formula, note the information required. Given the daily flow as 9 100 m³/d, it is necessary to calculate the surface area of the final clarifiers.

using area of a circle formula

$$A = \pi r^2 \quad \text{or} \quad \frac{\pi d^2}{4}$$

given a diameter of 14 m, the surface area of one final clarifier is

$$\frac{3.14 \ (14 \ m \ )^2}{4} = 153.9 \ m^2$$

However, there are two final clarifiers; therefore total clarifier surface area is

$$2 \times 153.9 \ m^2 = 307.8 \ m^2$$

$$\text{Upflow Rate} = \frac{9 \ 100 \ m^3/d)}{307.8 \ m^2}$$

$$= 29.6 \ m^3/m^2/d$$

SLUDGE VOLUME INDEX (SVI)

The Sludge Volume Index (S.V.I.) is defined as the volume, in millilitres, that is occupied by 1 gram of activated sludge after a 30 minute settling test. Normal activated sludge generally has an SVI value in the range of 70-125.

EXAMPLE

If the mixed liquor settled to 285 mL or 28.5% after the 30 minute settling test and the concentration of the mixed liquor suspended solids (MLSS) is 3 250 mg/L what is the SVI?

SOLUTION:

$$SVI^* = \frac{30 \text{ min. settling test results (mL) x 1 000}}{MLSS}$$

$$= \frac{285 \text{ ml x 1 000}}{3\ 250}$$

$$= 87.7$$

* Alternate formula $SVI = \dfrac{30 \text{ min settling test (mL)}}{MLSS \text{ in grams}}$

RESPIRATION RATES

The respiration rate, in the context of an activated sludge plant, is the rate at which the microorganisms within the aeration tanks use up oxygen. Another phrase for this process is Oxygen Uptake Rate. Respiration rates or uptake rates vary according to the solids concentration in the aeration tank. As a result, the uptake rate is frequently expressed as the "Specific Uptake Rate" (SUR) and this means the amount of oxygen utilized in one hour by one gram of mixed liquor volatile suspended solids.

<u>EXAMPLE</u>

Oxygen consumption of a mixed liquor was measured and recorded over a period of time. From the information provided below, prepare a graph and -

a)   calculate the <u>oxygen uptake rate</u>

b)   given a volatile suspended solids value of 2 400 mg/L calculate the <u>specific uptake rate</u> .

Time(min)	DO (mg/L)
0	7.8
1	7.7
2	7.3
3	6.8
4	6.4
5	6.0
6	5.4
7	4.8
8	4.3
9	3.7
10	3.0

a)   It can be seen from the record that the DO value at time zero is 7.8 mg/L and the value at time 10 minutes is 3.0 mg/L. By subtracting the lower DO value from the higher and dividing by the time interval, the uptake rate can be determined as follows:

$$\frac{7.8 \text{ mg/L} - 3.0 \text{ mg/L}}{10 \text{ min.}} = 0.48 \text{ mg } O_2/\text{L/min}$$

But the oxygen uptake rate is expressed in the units mg O_2/L/h

uptake rate = .48 mg O_2/L/min x 60 min/h

= 28.8 mg O_2/L/h

b)   Specific Uptake Rate (SUR) mg O_2/h /g   MLVSS

   = $\dfrac{\text{Uptake Rate}}{\text{MLVSS (g/L)}}$

   = $\dfrac{28.8 \text{ mg } O_2\text{/L/h}}{2.4 \text{ g/L}}$

   =   12 mg O_2/h /g   MLVSS

ORGANIC LOADING (BOD Volume Load)

      Organic loading of a trickling filter refers to the daily
mass of BOD entering the trickling filter volume. This
concept is expressed as

      Organic Loading = $\dfrac{\text{kg BOD/d}}{1\ 000 \text{ m}^2}$

EXAMPLE 1:

      A standard rate trickling filter has a diameter of 36 m
and a media depth of 2 m. The flow into the filter is 37.6
L/s with a BOD concentration of 85 mg/L. What is the
BOD loading per 1 000 m^3?

SOLUTION:

First we must determine the daily flow

Pumping rate   =   37.6 L/s

   Daily flow = $\dfrac{(37.6 \text{ L/s}) (86\ 400 \text{ s/d})}{1\ 000 \text{ L/m}^3}$

            =   3.25 x 1 000 m^3/d

Next we calculate kg BOD/day

   85 mg/L   =   (85 mg/L) (3.25 x 1 000 m^3/d)

         =   276.25 kg BOD/d

Because organic loading is a mass to volume relationship we must determine the volume of the trickling filter.

Diameter = 36 m
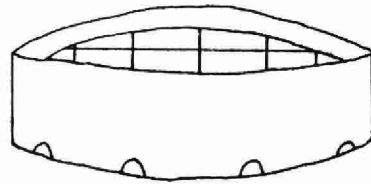
Height = 2 m

$$\text{Volume of cylinder} = \frac{\pi D^2}{4} \times H$$

$$\text{Volume} = (3.14)\ (36\ m)\ (36\ m)\ (2\ m)$$

$$= 8.14 \times 1\ 000\ m^3$$

Now we can utilize the relationship

$$\text{Organic Loading} = \frac{kg\ BOD/d}{1\ 000\ m}$$

$$= \frac{276.25\ kg\ BOD/d}{8.14 \times 1\ 000\ m^3}$$

$$= 33.94\ kg\ BOD/1\ 000\ m^3$$

ORGANIC LOADING

EXAMPLE 2:

An aeration tank has the following dimensions: 7 m x 17 m x 5 m. The flow to the aeration tank is 5 900 m³ with a BOD concentration of 70 mg/L. Calculate the BOD loading per 1 000 m³.

SOLUTION:

Calculate kg BOD/d

$$70\ mg/L = 70\ mg/l \times 5.9 \times 1\ 000\ m^3/d$$

$$= 413\ kg\ BOD/d$$

39

Next, determine volume of aeration tank.

$$V = L \times W \times H$$

$$= (7\ m)\ (17\ m)\ (5\ m)$$

$$= 595\ m^3$$

Since Organic Loading $= \dfrac{kg\ BOD/d}{aeration\ tank\ volume/1\ 000\ m^3}$

$$= \dfrac{413\ kg\ BOD/d}{0.595 \times 1\ 000\ m^3}$$

$$= 694.1\ kg\ BOD/1\ 000\ m^3$$

SECTION E

WORKING SECTION FOR ACTIVATED SLUDGE PROCESS

(1)   A 50 mL aliquot of mixed liquor is filtered for a suspended solids analysis. The mass of the paper is 0.174 g. After filtering and drying, the paper has a mass of 0.324 g. What is the <u>MLSS</u> concentration?

(2)   Given a raw sewage flow of 4 500 m^3 and a BOD in the raw sewage of 150 mg/L calculate the <u>kg of BOD</u> per day entering the aeration section assuming a 20% reduction in BOD across the primary clarifiers.

41

(3) Given that a plant has a daily flow of 4 500 m^3 and an average primary effluent BOD_5 of 150 mg/L, mixed liquor volatile suspended solids (MLVSS) of 1 500 mg/L and an area tank volume of 900 m^3, calculate the F/M ratio .

(4) If the uptake rate is 20 mg O_2/L/h and the MLVSS is 4 000 mg/L, what is the specific uptake rate?

(5)   A 460 m aeration tank contains 4 000 mg/L MLVSS.
       The return sludge concentrtion is 12 000 mg/L. What
       volume of sludge should be wasted in order to
       reduce the <u>MLSS</u> to 3 000 mg/L?

(6)   Calculate the MLVSS and SVI using the following
       information:

       a)   Mass of paper   =   0.4004 g

       b)   Mass of paper   =   0.5186 g
            + solids

       c)   Sample volume   =   50 mL

       d)   30 min. settling test =   21%

43

(7)   A 250 mL sample of final effluent is filtered for a
        suspended solids analysis. The mass of the paper
        is 0.156 0 g. After filtering and drying, the mass
        of the paper is 0.157 2 g. Express the suspended
        solids concentration in mg/L.

(8)   An aeration tank has a capacity of 2 270 m^3 . If
        the MLSS is 3 000 mg/L, what is the mass of the
        solids expressed in kg?

(9)   The MLSS concentration in a 910 m^3 aeration tank
        is 4 000 mg/L. This activated sludge contains
        75% volatile suspended solids. Express the MLVSS
        in kg.

(10) A flow of 7 730 m³/d is entering a conventional activated sludge treatment plant. The BOD concentration in the raw sewage is 265 mg/L. If the primary treatment stage of the process removes 23% of the BOD and the F/M ratio in the aerator is 50 kg BOD/1 000 kg MLVSS, how many kg MLVSS should be maintained in the areator?

(11) <u>Given</u>

An aeration tank is 27 m long, 20 m wide, water depth is 3 m

MLSS = 2 550 mg/L

Flow = 11 370 m³/d

Daily Waste Volume = 100 m³

Waste AS Suspended Solids = 9 000 mg/L

Suspended Solids concentration in effluent = 15 mg/L

Calculate SRT

EXAMPLE CALCULATIONS FOR
ANAEROBIC DIGESTION PROCESS

Volatile Acid/Alkalinity Ratio

The volatile acid/alkalinity ratio is the key to successful digester operation. As long as the volatile acids remain low and the alkalinity stays high, anaerobic sludge digestion will occur in a digester. When the ratio starts to increase, corrective action must be taken immediately. This is the first warning that trouble is starting in a digester. If corrective action is not taken immediately or is not effective, eventually the CO content of the digester gas will increase, the pH of the sludge in the digester will drop, and the digester will become sour.

$$\text{Volatile Acid/Alkalinity Ratio} = \frac{\text{Volatile Acids mg/L}}{\text{Total Alkalinity mg/L}}$$

Example:

A recirculated sludge from a primary digester has a volatile acids content of 300 mg/L and a total alkalinity of 2 000 mg/L. What is the volatile acid/alkalinity ratio?

Solution: Using the formula above.

$$\text{Volatile acid/alkalinity ratio} = \frac{300 \text{ mg/L}}{2\ 000 \text{ mg/L}}$$

$$= \quad 0.15$$

Solids Calculations:

Samples are collected of the raw sludge, recirculated sludge, and supernatant. Each sample is tested for total solids and volatile solids. The information from these tests is used to determine the mass of solids handled through the system, the digester loading rates, and the percent of reduction of the organic matter destroyed by the digester. All of these tests are necessary for the maintenance of efficient digester operation. Volumes of sludge are needed to determine the mass of solids handled through the system.

A.   Raw Sludge

If the 12.75 m^3 of raw sludge pumped by the piston pump
contains 6.5% total solids and had a volatile content of 68%:

    1.   What is the mass of the solids contained in the
         raw sludge?

    2.   What is the mass of the volatile solids?

Example

    Sludge Pumped   =   12.75 m^3

    Total Solids   =   6.5%

    Volatile Solids =   68%

Mass of total solids (kg)   = volume of raw sludge x % solids
                              as decimal x $\frac{1\ 000\ kg}{m3}$

                            = (12.75 m)   (0.065) $\frac{(1\ 000\ kg)}{m^3}$

                            = 828.75 kg during pumping period

Volatile Solids (kg)   =   % volatile solids as decimal x total
                           solids (kg)

                       =   (0.68)   (828.75 kg)

                       =   563.55 kg of volatile solids
                           during pumping period

B.   Recirculated Sludge

    Laboratory tests indicate that the total solids in a
recirculated digested sludge sample was 4.5% and contained
54.2% volatile solids content. This indicates that the
process is reducing the volatile solids content of the sludge,
but the 4.5% total solids content is lower than that of the
raw sludge being pumped to the digester. The reduction is a
result of the conversion of a substantial portion of the
volatile solids in the raw sludge to methane, carbon dioxide,
and water. Therefore, the reduction in total solids comes
from some of the total solids being coverted to gas and some
of the total solids being washed out in the supernatant.

The reduction of volatile solids that has occurred in the primary digester is arrived at mathematically by the following formula:

$$P = \frac{R - D}{R - (R \times D)} \times 100\% = \frac{In - Out}{In - (In \times Out)} \times 100\%$$

P = Percent Reduction of Volatile Solids

In = R = Percent Volatile Solids in Raw Sludge

Out = D = Percent Volatile Solis in Digester Sludge

Example:

In = 68% Volatile Matter in Raw Sludge

Out = 54.2% Volatile Matter in Digester Sludge

$$P = \frac{In - Out}{In - (In \times Out)} \times 100\%$$

$$= \frac{0.68 - 0.54}{0.68 - (0.68 \times 0.54)} \times 100\%$$

$$= \frac{0.14}{0.31} \times 100\%$$

$$= 0.45 \times 100\%$$

$$= 45\%$$

C.   Secondary Digested Sludge

Laboratory results indicate that a digested sludge total solids sample was 9.6% and 42.8% volatile solids content. The raw sludge volatile solids content was 68%. The overall percent reduction, P, could then be arrived at by using the formula,

$$P = \frac{In - Out}{In - (In \times Out)} \times 100\%$$

$$= \frac{(0.68 - 0.43)}{0.68 - (0.68 \times 0.43)} \times 100\%$$

$$= \frac{0.25}{0.39} \times 100\%$$

$$= 0.64 \times 100\%$$

$$= 64\%$$

48

What is actually happening in the calculation of the percent reduction of volatile matter may be visualized by the following example. Start with 200 m^3 of raw sludge solids consisting of 75% volatile organic solids and 25% inorganic solids. After digestion, 100 m^3 of volatile matter has been converted to methane, carbon dioxide, and supernatant water containing solids, nitrogen, and a COD. The remaining digested sludge consists of 50 m^3 volatile solids and 50 m^3 of inorganic solids.

BEFORE DIGESTION   AFTER DIGESTION

200 m^3 Raw Sludge CH_4 CO_2 H_2S H_2O

75% Volatile Solids   150 m^3 100 m^3

                                          50 m^3

25% Inorganic Solids   50 m^3 50 m^3
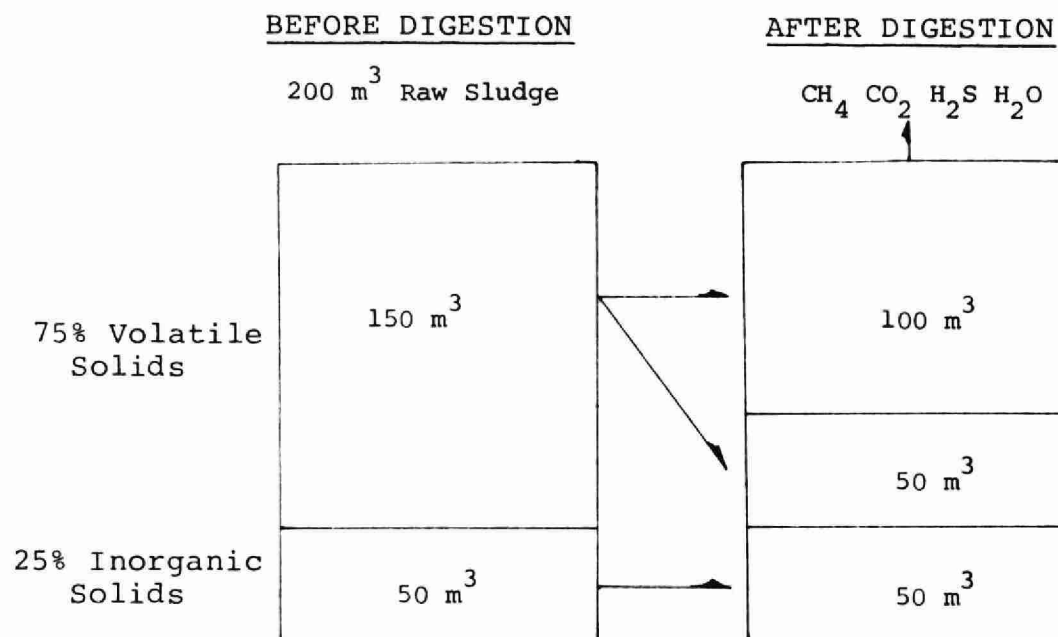
D.   Computing Digester Loadings

Digester loadings are reported as kg of volatile matter per cubic metre of digester volume per day. The loading rate should be around 2.4 kg to 5.6 kg of volatile solids per cubic meter in a heated and mixed digester. For an unmixed or cold digester, the loading rate should not exceed 0.8 kg of volatile matter per cubic metre, assuming that each cubic meter contains approximately 8.0 kg of predigested solids.

A 10 m diameter and 7 m water depth digester has a raw sludge volume of 40 m^3 at 6.5% total solids and 68% volatile solids. It was determined that there were 1 768 kg of volatile solids added to the digester per day. Calculate the digester loading.

Example

Digester Loading = $\dfrac{\text{kg of volatile solids /d}}{\text{Volume of Digester (m}^3\text{)}}$

$= \dfrac{1\ 768 \text{ kg volatile solids /d}}{549.8 \text{ m}^3}$

$= 3.2$ kg/m^3/d of volatile solids

E.   Volatile Solids Destroyed

The data is reported as kg of volatile solids destroyed per cubic meter of digester capacity per day. Using the same data from previous example and starting from the beginning with 40 m at 6.5% total solids, and 68% volatile solids assume a volatile solids reduction of 50%.

Volatile Solids Destroyed
in kg/m /d
$= \dfrac{\text{Volume of raw sludge x \% total solids x \% volatile x \% reduction x 1 000 kg/m}^3}{\text{Digester Volume (m}^3\text{)}}$

$= \dfrac{(40 \text{ m}) (0.065) (0.68) (0.5) (1\ 000 \text{ kg/m}^3)}{549.8 \text{ m}^3}$

$= \dfrac{884 \text{ kg}}{549.8 \text{ m}^3\text{/d}}$

Volatile solids destroyed = 1.6 kg/m^3/d

F.   Computing Gas Production

Digester gas data should be recorded in cubic metres produced per day by the digestion system, as recorded daily from the gas meter. The carbon dioxide (CO_2) content should normally be tested once or twice a week.

The change of CO_2 in the gas is an indicator of the condition of the digester. Good digester gas will have a CO_2 content of 30 to 35%. The volatile acid/alkalinity relationship will start to increase <u>before</u> the carbon dioxide (CO_2) content begins to climb. If the CO_2 content exceeds 42%, the digester is considered in poor condition and the gas is close to the burnable limit (44 to 45% CO_2).

Gas production should range between 0.44 m^3 and 0.75 m^3 per kg of volatile solids destroyed in the digesters.

Example

A digester produces 525 m^3/d of gas. If the mass of the volatile solids destroyed per day was 884 kg. Calculate the gas production per kg of destroyed volatile solids?

Solution: $= \dfrac{\text{Gas Produced} \quad \text{m}^3/\text{d}}{\text{Destroyed Volatile Solids} \quad \text{kg/d}}$

$= \dfrac{525 \text{ m}^3/\text{d}}{884 \text{ kg/d}}$

Gas Production = 0.59 m^3/kg

Anaerobic Digestion Process Calculations
(Imperial Measure)

EXAMPLE

Given

1. Digester volume (V)   = 1 500 000 gal or (240 385 ft^3)

2. Daily Sludge Feed (Q) = 55 000 gal.

3. Feed Sludge TS   = 5.2%
   Feed Sludge TVS   = 67%

4. Digested Sludge Total Solids (TS)   = 2.9%

   Digested Sludge Total Volatile Solids
        (TVS)   = 52.3%

5. Gas Production   = 140 000 ft^3/d

Determine

A. Digester retention time (in days)

   Solution:

   $\dfrac{V}{Q} = \dfrac{5\ 500\ 000}{55\ 000} = 27.3$ d

B. Pounds of volatile solids applied to digester per day

Solution:

$$55\ 000 \times {}^{*}10 \times \frac{5.2}{100} \times \frac{67}{100} = 19\ 162\ \text{lb/d}$$

* gallons/d x 10 (to convert to lbs/d)

   x $\frac{5.2}{100}$ (to convert to lbs of TS/d

   x $\frac{67}{100}$ (to convert answer to lbs of TVS/d)

C. Digester loading (lb. TVS/ft /d)

Solution:

$$\frac{55\ 000 \times 10 \times \frac{5.2}{100} \times \frac{67}{100}}{240\ 385} = 0.08\ \text{lb/TVS/ft /d}$$

i.e. Calculate lbs TVS applied per day as in question B and divide answer by digester volume in ft .

D. % solids reduction

Solution:

$$\% \text{ reduction} = 100 \left[1 - \frac{33 \times 52.3}{67 \times 47.7} \right] = 46\%$$

i.e. $100 \left[1 - \frac{\% \text{ ash in feed} \times \% \text{ TVS in digested sludge}}{\% \text{ TVS in feed} \times \% \text{ ash in digested sludge}} \right]$

where % ash = 100 - % TVS

52

E. Specific gas production (ft^3 gas/lb TVS destroyed)

<u>Solution:</u>

$$\frac{140\ 000}{19\ 162 \times 0.46} = 15.9 \text{ ft}^3/\text{lb TVS destroyed}$$

i.e. $\dfrac{\text{daily gas production in ft}^3}{\text{TVS applied daily x \% TVS reduction}}$

Anaerobic Digestion Process

1. A sludge sample taken from a primary digester
    was tested and the following was found.

    Total Alkalinity   2 500 mg/L
    Volatile Acids   270 mg/L

    Calculate the volatile acid/alkalinity ratio.

2. During a 24 hr. period, 15 000 L of raw sludge with
    a total solids concentration of 5.7% and a volatile
    solids content of 71% was pumped to a digester. What
    is the mass of the volatile solids pumped?

3. Calculate the reduction of volatile solids in a
    digester if the raw sludge volatile solids was
    69% and the digested sludge volatile solids was
    44%.

4. What is the organic loading of a digester with 600 m³ volume, receiving a raw sludge that has a volatile solids content of 62% and a total solids concentration of 5.9%? The volume of raw sludge pumped is 50 m³ daily.

5. Using the data from Question 4, calculate the the amount of volatile solids destroyed if the volatile solids reduction is 49%.

6. 900 m³ of digester gas is burned daily in the heat exchanger boiler, while 150 m³ of gas is burned at the waste gas burner. If 1 750 kg of volatile solids are destroyed daily, what is the gas production (m³/kg)?

7. A sludge digestion facility has the following
    characteristics.

    a) Digester volume ...   2 250 m^3
    b) Raw sludge pumped daily ...   140 m^3
    c) Raw sludge total solids ...   6%
    d) Raw sludge volatile solids ...   67%
    e) Digested sludge total solids ...   5.7%
    f) Digested sludge volatile solids..   51%
    g) Gas produced daily ...   1 300 m^3/d

    Determine the following using the data given:

    i)   Detention time in days.

    ii)   Digester Organic Loading.

    iii) % reduction of volatile solids.

iv) Volume of gas produced per kg of volatile
solids destroyed.

FILTER LOADING RATE

The "filter loading rate" is expressed as L or m^3 of water applied to each m^2 of surface area. This could also be described as the amount of water flowing down through each m^2 of filter surface. Filter design loading rates are expressed as $m^3/m^2.h^{-1}$ and $L/m^2.s^{-1}$.

$$\text{Filter loading rate} = \frac{m^3/d \text{ Flow}}{m^2 \text{ Filter Area}} \quad \frac{24 \text{ h}}{d}$$

NOTE: Design loading rates for filters are expressed in US gals at present. Using conversion factors to obtain S.I. units is necessary when studying American designed filters. Typical loading rates are shown below:

Rapid sand filter - 1.36 $L/m^2.s^{-1}$ (2 US gpm/ft^2)

Dual Media (coal/sand)- 0.136-0.272 $L/m^2.s^{-1}$ (0.2-0.4 US gpm/ft^2)

Multi Media (coal/sand/garnet) - 3.41 - 6.82 $L/m^2.s^{-1}$ (5-10 US gpm/ft^2)

Example

A rapid sand filter is 10 m wide and 15 m long. If the flow through the filter is 17 630 m^3/d what is the filter loading rate in $L/m^2.s^{-1}$.

First, convert the flow to L/s

$$\frac{17\ 630\ m^3}{d} \quad \times \quad \frac{1\ 000\ L}{m^3} \quad \div \quad \frac{86\ 400\ s}{d} \quad = \quad \frac{204\ L}{s}$$

Then express the filter loading rate mathematically as:

$$\text{Filter loading rate} = \frac{flow}{filter\ area}$$

$$= \frac{204\ L/s}{150\ m^2}$$

$$= 1.36\ L/m^2.s^{-1}$$

FILTER BACKWASH RATE

There are two methods that may be used to calculate the filter backwash rate.

a) Filter Backwash Rate = $\dfrac{\text{flow L/s}}{\text{filter area m}^2}$

b) Filter Backwash Rate = $\dfrac{\text{meters of water rise}}{\text{hour}}$

NOTE: As with filter loading rates, filter backwash rates are also expressed in U.S. gals at present. Rates are shown below:

Minimum   10.2 $L/m^2.s^{-1}$ (15 US gpm/ft^2)

Maximum   15.3 $L/m^2.s^{-1}$ (22.5 US gpm/ft^2)

This is equivalent to a rise in the water level of 36.67 m/h (2 ft/min) to 55.0 m/h (3 ft/min).

EXAMPLE 1

A rapid sand fitler is 10 m wide and 12 m long. If backwash water is flowing upward at a rate of 1.56 m/s, what is the backwash rate in $L/m^2.s^{-1}$?

Flow = $\dfrac{1.56 \text{ m}}{s}$ x $\dfrac{1\ 000 \text{ L}}{m^3}$ = 1 560 L/s

Therefore, there are 1 560 L/s flowing upward through a filter with a surface area of 120 m^2 .

This can be written mathematically as:

Filter backwash rate: = $\dfrac{\text{flow}}{\text{filter area}}$

$\qquad\qquad\qquad$ = $\dfrac{1\ 560 \text{ L/s}}{120 \ m^2}$

$\qquad\qquad\qquad$ = 13 $L/m^2.s^{-1}$

EXAMPLE 2

A mixed-media filter is 8 m wide and 11 m long. If the filter receives a backwash flow of 84 000 m^3/d, what is the filter backwash flow rate in $L/m^2 \cdot s^{-1}$?

As in the last example, first convert the backwash flow to L/s:

$$\frac{84\ 000\ m^3}{d} \times \frac{1\ 000\ L}{m^3} \div \frac{86\ 400\ s}{d} = \frac{972.22\ L}{s}$$

Filter backwash rate = $\dfrac{flow}{filter\ area}$

$$= \frac{972.22\ L/s}{(8\ m)\ (11\ m)}$$

$$= \frac{972.22\ L/s}{88\ m^2}$$

$$= 11.05\ L/m^2 \cdot s^{-1}$$

Filter backwash rates, as noted earlier, are sometimes expressed in terms of vertical rise of water in a time interval measured in hours, for example, metres per hour (m/h). The units of measure are directly related to each other as shown by the following proof:

$$= \frac{11.02\ L/m}{s} \times \frac{3\ 600\ s}{h} \div \frac{1\ 000\ L}{m^3}$$

$$= \frac{39.672\ m^3/m^2}{h}$$

$$= \frac{39.672\ m}{h} \quad or \quad 39.672\ m/h$$

For simplication, a conversion factor can be extracted from the above proof.

$$\frac{3\ 600\ s}{h} \div \frac{1\ 000\ L}{m^3}$$

$$= 3.6\ s/m^3 \Big/ h/L$$

Then by substitution back into the proof:

$$\frac{11.02\ L/m^2}{s} \times \frac{3.6\ s/m^3}{h/L} = \frac{39.672\ m^3/m^2}{h} = \frac{39.672\ m}{h}$$

Surface Water

1. A rapid sand filter is 5 m wide and 10 m long. If the backwash water flow rate is 55 600 m^3/d, determine the filter backwash rate in m/h.

2. What is the filter backwash rate in $L/m^2.s^{-1}$ corresponding to a filter backwash rate of 37 m/h?

3. During operation of a multi media sand filter, the operator measured the flow rate to be 14.4 m/h. Express this filter flow rate in $L/m^2.s^{-1}$.

4. A rapid sand filter is 4 m wide and 7 m long. If the flow through the filter is 3 300 m^3, what is the filter loading rate?

   a) $L/m^2.s^{-1}$

   b) m/h

Chemical Feeding & Preparation of Stock Solutions

SOLUTIONS

A solution consists of two components, a solvent which is the dissolving medium and a solute which is the substance dissolved. The solute is dispersed as molecules and ions and the distribution of the solute is perfectly homogenous throughout the solution. A common example of solvent and solute is water and sugar.

A concentrated solution is one which contains a relatively large amount of solute per unit volume of solution. A dilute solution is one which contains a relatively small amount of solute per unit volume of solution. The words "strong" and "weak" should not be used when referring to the concentration of a solution. Strong and weak are terms that are more properly used to describe the chemical activity of a substance.

Solution Preparation - Jar Tests

Jar tests are used to determine correct chemical dosages for such chemicals as alum, ferric chloride, activated silica. These chemicals are utilized in water treatment for coagulation and flocculation of colloidal particles and are used in wastewater treatment for chemical precipitation of phosphorous. The jar test simulates, on a small scale, the activities going on in the full scale treatment process. Varying amounts of the chemicals are compared to see which chemical and dosage, best accomplishes coagulation and flocculation in water treatment and the chemical precipitation of phosphorous in sewage treatment.

Stock solutions of coagulants, coagulant aids and other chemicals, should be prepared at concentrations such that quantities suitable for use in the jar tests can be measured accurately and conveniently.

When making stock solutions from dry chemicals, a very straight forward approach is used. Dissolve 1 gram of solute in 1 litre of water to obtain a 1 g/L solution. Using the solution is easy because 1 gram of solute is contained in 1 litre solvent; therefore 1 mg of solute is contained in 1 mL of solvent. When a jar test requires dosages of solution, simply fill a pipette to the required dosage and the proper mass of chemical will be present in the contained volume of the solution.

EXAMPLE: One gram of soda ash is contained in one litre of distilled water. We now have a 1 g/L solution of soda ash. A jar test requires dosages of 5 mg/L, 10 mg/L, 15 mg/L, 20 mg/L, 25 mg/L and one jar is a blank. How many mL of soda ash solution are required for each dosage?

1 g/L soda ash solution = 1 mg of soda ash/mL of solution

5 mg of soda ash / 5 mL of solution

Required dosages = 5 mg/L, 10 mg/L 15 mg/L, 20 mg/L, 25 mg/L
mL of solution   = 5 mL, 10 mL, 15mL, 20 mL, 25 mL

Remember that the dosage is being added to 1 litre of raw water so now the dosage is expressed as 5 mg of soda ash/L of raw water. Conveniently 5 mg/L.

When preparing solutions from liquid concentrates, the amount of chemical present in the solution needs to be known as well as the relative density of the original solution. The concentration and relative density are usually found on the product label.

A concentrated alum solution contains 48.5% alum and has a relative density of 1.35. To prepare a 1 g/L solution from the concentrated alum, we need to find out how many mL of concentrate contains 1 gram of pure alum.

1 mL of concentrated
solution contains   = 1.35 x 0.485 g of alum

                        = 0.65 g of alum

Then the volume of 1 g of alum is:

$$= \frac{1\ g}{0.65\ g/mL}$$

$$= 1.54\ mL$$

1.54 mL of concentrated alum contains 1 gram of alum. To make a 1 g/L solution of alum simply dilute 1.54 mL of concentrated solution to one litre with distilled water. Dosages can now be applied to jar tests as described earlier in the section on Dry Chemical Solution Preparation.

63

CHEMICAL FEEDING

Water and Wastewater Operations

After jar tests have been carried out, the type of chemical dosage and point of application best suited to the characteristics of the water or sewage to be treated, should easily be established. The next step is to feed the chemical at the dosage determined by the jar tests into the full scale treatment facility. The operator will be faced with using a dry chemical or a liquid chemical which will be fed into the process by means of a dry chemical feeder or a liquid chemical feeder. If feeding dry chemicals, the feeder will be calibrated, most likely, in grams per minute or, if liquid chemicals are being utilized, in millilitres per minute. Following is a detailed approach to establishing feed rates for chemicals.

EXAMPLE: A daily flow of 16 000 m³/d requires a dosage of 13 mg/L of ferric chloride for phosphorous removal. Calculate the flow rate in mL/min.

$$\text{Ferric chloride} = 1.67 \text{ kg/L}$$
$$\text{Fe+} = 13.7\% \text{ by mass in solution.}$$

Step 1. Determine the mass of solution required (kg/d)

$$\text{sol'n required} = \frac{\text{dosage x flow}}{\text{Decimal fraction of active ingredients}}$$

$$\text{sol'n required} = \frac{(13 \text{ kg/1 000 m}^3) (16 000 \text{ m}^3/\text{d})}{0.137}$$

sol'n required = 1 518.25 kg/d

Step 2: Determine volume (L/d) of solution required.

1 litre of solution has a mass of 1.68 kg. It is necessary to divide the total mass of solution by the relative density of the solution.

$$\text{volume of sol'n} = \frac{\text{mass of solution}}{\text{relative density}}$$

$$\text{volume of sol'n} = \frac{1 518.25 \text{ kg/d}}{1.67 \text{ kg/L}}$$

$$= 909.1 \text{ L/d}$$

Step 3: Now we convert the volume of solution required into the flow rate by the following conversion factors.

Flow Rate = $\dfrac{909.1 \text{ L}}{\text{d}}$ x $\dfrac{1\ 000\ \text{mL}}{\text{L}}$ ÷ $\dfrac{1\ 440\ \text{min}}{\text{d}}$

Flow Rate = 631.32 mL/min

EXAMPLE: A water plant with a daily flow of 1 700 m³ doses at 55 mg/L with a 48.5% liquid alum solution. What is the feed rate in mL/min?

Data: Flow 1 700 m³/d
48.5% alum by mass as active ingredient
1.34 g/cm³ relative density

mass of sol'n req'd = $\dfrac{(55 \text{ kg}/1\ 000\ \text{m})\ (1\ 700\ \text{m}^3/\text{d})}{0.485}$

= 192.8 kg/d

volume of sol'n = $\dfrac{192.8 \text{ kg/d}}{1.34 \text{ kg/L}}$

= 143.9 L/d

Flow Rate = $\dfrac{143.9 \text{ L}}{\text{d}}$ x $\dfrac{1\ 000\ \text{mL}}{\text{L}}$ ÷ $\dfrac{1\ 440\ \text{min}}{\text{d}}$

= 99.9 mL/min

It is important to mention that feed rates are properly expressed as mL/s but using mL/min is convenient to calibrate and measure. To obtain mL/s simply divide mL/min by 60 s/min as shown with the above example.

$\dfrac{99.9 \text{ ml}}{\text{min}}$ ÷ $\dfrac{60 \text{ s}}{\text{min}}$

= 1.665 mL/s

CALCULATION OF FEED RATES USING A FORMULA

An alternate method of calculating feed rates in mL/min is through the use of a formula that takes into account all variables such as chemical concentrations, optimum dosages, plant flow, etc. Previously the long method was exemplified, however for practical applications the formula method is valid.

Figure J-1 is a mathematical method for determining feed rates of chemical addition in millilitres per minute (mL/min), the normal units found on most liquid chemical feeders. These units of feed rate are utilized as they provide a convenient volume and time scale for calibration and accurate feeding of highly expensive and sometimes hazardous chemicals.

The formula takes into account variations in concentrations of chemicals and their relative densities. Once proper dosage has been established through jar tests and daily flows from the flow chart and the variations in the chemical's composition from the delivery tag this formula will provide the correct feed rate in millilitres per minute .

Feed Rate Formula (mL/min)

mL/min =

$$\frac{\text{Dosage (mg/L)} \times \text{Flow/1 000 m}^3\text{/d} \times 1\ 000\ \text{mL/L}}{\text{\% active chemical} \quad \times \quad \text{relative density} \times 1\ 440\ \text{m/d}}$$
as decimal fraction

This formula contains conversion factors that are constants. These are indicated by the boxes in the formula. For ease of calculation, we can reduce the two conversion factors to one. The constant would be:

$$\frac{1\ 000\ \text{mL/L}}{1\ 440\ \text{min/d}} = 0.694$$

As a result, we can simplify the feed rate formula. Using the previous example, determination of the alum feed rate, the calculation can be shown as:

mL/min = $\dfrac{\text{Dosage mg/L} \times \quad \text{Flow/1 000 m}^3\text{/d} \times 0.694}{\text{\% Active chemical} \quad \times \quad \text{Relative Density}}$
as Decimal Fraction

= $\dfrac{(55\ \text{mg/L})\ (1.7 \times 1\ 000\ \text{m /d})\ (0.694)}{(0.485)\qquad (1.34\ \text{kg/L})}$

= 99.8 mL/min

66

STOCK SOLUTIONS AND CHEMICAL FEED RATES

1. How many mL of ferric chloride are needed to
    prepare 1 000 mL of a 1 g/L solution of ferric
    chloride if the concentrated solution is 42.3%
    by mass and the relative density is 1.42?

2. How many mL of alum are required to
    make up 1 L of a 1 g/L solution for jar tests if
    the alum is 48% by mass and the relative density
    is 1.34?

3. In a wastewater treatment plant with an average daily
    flow of 11 250 m^3/d, alum is being used for
    phosphorous removal at a dosage of 450 mg/L.   What
    alum flow rate, measured in mL/min is needed?
    (USE LONG METHOD FOR CALCULATION)

    DATA: Liquid alum has a relative density of 1.35 kg/L
            Liquid alum contains 48% by mass alum as
            $Al_2(SO_4)_3 .14H_2O$

4. In a water treatment plant both alum and activated
    silica are being used in the coagulation stage to
    help precipitate the collidal suspensions. Jar
    tests indicated that 50 mg/L alum and 5.5 mg/L
    activated silica is the optimum dosage. Calculate,
    using the formula, the feed rate needed for each
    chemical in mL/min.

    DATA:
      Flow   1 000 m^3/d
      Liq. Alum Relative Density   1.35 kg/L
      Liq. alum contains   48.5% Al_2SO_4.14 H_2O
      Act. Silica Relative density 1 kg/L
      Act. Silica contains   1% solution

5. A plant has an average daily flow of 17 750
    m^3/d and is dosing ferric chloride for phosphorus
    removal at 15 mg/L Fe^{+3}. What feed rate measured
    in mL/min is needed? Also how many L/d of ferric
    chloride is needed?

DATA:

    Liq. $FeCl_3$ relative density   1.4 kg/L
    $FeCl_3$ contains   14.0% Fe^{+3}
    $FeCl_3$ contains   41.5% FeCl

6. The dry alum dosage rate is 12 mg/L at a water treatment
    plant. The flow rate at the plant is 13 500 m^3/d.
    How many kilograms per day of alum are required?

APPENDIX I

CONVERSION FACTORS

IMPERIAL UNIT	MULTIPLIER	SI UNIT
acre	X 4 046.9 ⟶ ⟵ 2.471 1 x 10 X	m^2
acre	X 0.404 69 ⟶ ⟵ 2.471 1 X	ha
acre-ft	X 1 233.5 ⟶ ⟵ 8.107 X	m^3
Btu	X 1.055 ⟶ ⟵ 0.947 8 X	kJ
Btu/hr/sq ft	X 3.154 ⟶ ⟵ 0.317 0 X	$J/m^2.s$
Btu/lb	X 2.326 ⟶ ⟵ 0.430 0 X	kJ/kg
cfm	X 4.719 X 10 ⟶ ⟵ 2 119 X	m^3/s
cfs	X 0.028 32 ⟶ ⟵ 35.315 X	m^3/s
cfs/acre	X 0.069 97 ⟶ ⟵ 14.29 X	$m^3/ha.s$*
cu ft	X 0.028 32 ⟶ ⟵ 35.315 x	m^3
cu ft	X 28.32 ⟶ ⟵ 0.035 315 X	1*
cu in	X 16.39 ⟶ ⟵ 0.061 02 X	cm^3
cu yd	X 0.764 6 ⟶ ⟵ 1.308 X	m^3
°F	X 0.555 (F-32) ⟶ ⟵ 1.8 (C) + 32 X	°C
°C	+ 273 ⟶ ⟵ 273 -	K
ft	X 0.304 8 ⟶ ⟵ 3.281 X	m

IMPERIAL UNIT	MULTIPLIER	SI UNIT
ft-lb	X 1.356 ⟶ ⟵ 0.737 6 X	J
gal	X 3.785 ⟶ ⟵ 0.264 2 X	L*
gal	X 0.003 785 ⟶ ⟵ 264.2 X	m^3
gpd/acre	X 0.009 353 ⟶ ⟵ 106.9 X	m^3/ha.d*
gpd/ft	X 0.012 42 ⟶ ⟵ 80.52 X	m^3/m.d*
gpd/sq ft	X 0.040 74 ⟶ ⟵ 24.55 X	m^3/m^2.d*
gpm	X 6.308 X 10 ⟶ ⟵ 1.585 X 10 X	m^3/s
gpm	X 0.063 08 ⟶ ⟵ 15.85 X	L/s*
gpm/sq ft	X 0.679 02 ⟶ ⟵ 1.473 X	L/m^2.s*
hp	X 0.745 7 ⟶ ⟵ 1.341 X	kW
hp-hr	X 2.685 ⟶ ⟵ 0.372 5 X	MJ
in	X 25.400 ⟶ ⟵ 0.039 37 X	mm
lb (force)	X 4.448 ⟶ ⟵ 0.224 8 X	N
lb (mass)	X 0.453 6 ⟶ ⟵ 2.205 X	kg
lb/day/acre -ft	X 0.367 7 ⟶ ⟵ 2.719 6 X	g/m^3.d*
lb/1000 cu ft	X 16.02 ⟶ ⟵ 0.062 43	g/m^3
lb/day/acre	X 0.112 1 ⟶ ⟵ 8.922 X	g/m^3.d*

IMPERIAL UNIT	MULTIPLIER	SI UNIT
lb/day/ cu ft	X 10.02 ⟶ ⟵ 0.062 43	kg/m^3.d*
lb/day/ sq ft	X 4.883 ⟶ ⟵ 0.204 8 X	kg/m^2.d*
lb/ft	X 1.488 ⟶ ⟵ 0.672 0 X	kg/m
lb/mil gal	X 0.119 8 ⟶ ⟵ 8.344 X	g/m^3
mil gal	X 3 785 ⟶ ⟵ 2.642 X 10 X	m^3
mgd	X 3 785 ⟶ ⟵ 2.642 x 10 X	m^3/d*
mgd	X 0.043 8 ⟶ ⟵ 22.83 X	m^3/s
mgd/acre	X 1.082 x 10 ⟶ ⟵ 9.238 X 10	m^3/m^2.s
mile	X 1.609 ⟶ ⟵ 0.621 4 X	km
ppm (by weight)	essentially essentially	mg/L*
psf	X 0.047 88 ⟶ ⟵ 20.89 X	kN/m^2
psf	X 4.882 ⟶ ⟵ 0.204 8 X	kg/m^2
psi	X 6.895 ⟶ ⟵ 0.145 0 X	kN/m^2
psi	X 0.070 3 ⟶ ⟵ 14.22 X	kgf/cm^2*
sq ft	X 0.092 9 ⟶ ⟵ 10.76 X	m^2

IMPERIAL UNIT	MULTIPLIER	SI UNIT
sq in	X 645.2 ——► ◄—— 0.001 55 X	mm²
sq miles	X 2.590 0 ——► ◄—— 0.386 1 X	km²
yard	X 0.914 4 ——► ◄—— 1.094 X	m
mgd	X 4.381 x 10 ——► ◄—— 22.830 X	m³/s
gpm	X 5.450 ——► ◄—— 0.183 5X	m³/d*
cfs	X 28.450 ——► ◄—— 0.035 15 X	L/s*
cu ft/mil gal	X 0.007 482 ——► ◄—— 133.7 X	L/m³*
lb/mil gal	X 0.119 8 ——► ◄—— 8.344 X	g/m
cfm/lin ft	X 1.549 ——► ◄—— 0.645 8 X	L/m.s*
sq ft/ft	X 0.304 8 ——► ◄—— 3.281 X	m²/m
gpd/lin ft	X 0.012 42 ——► ◄—— 80.53 X	m³/m.d*
gpd/lin ft	X 1.437 X 10 ——► ◄—— 695 8 X	L/m.s*
ft/hr	X 0.084 67 ——► ◄—— 11.810 X	mm/s
ft/hr	X 0.304 8 ——► ◄—— 3.281 X	m/h*
lb/day/sq ft	X 4.883 ——► ◄—— 0.204 8 X	kg/m².d*
lb/day/sq ft	X 0.05 651 ——► ◄—— 17.70 X	g/m².s
lb/day/1000 sq ft	X 4.883 ——► ◄—— 0.204 8 X	g/m².d*

IMPERIAL UNIT	MULTIPLIER	SI UNIT
lb/day/lb	X 1.00 ➤ ◄ 1.00 X	kg/kg.d*
cu ft/lb	X 0.062 43 ➤ ◄ 16.02 X	m^3/kg
cu ft/gal	X 0.133 7 ➤ ◄ 7.481 X	m^3/m^3
cfm	X 0.417 9 ➤ ◄ 2.119 X	L/s*
cfm	X 4.719 X 10 ➤ ◄ 2 119 X	m^3/s
lb/hr/cu ft	X 16.02 ➤ ◄ 0.062 43	$kg/m^3.h$*
lb/hr/cu ft	X 0.004 450 ➤ ◄ 224.7 X	$g/m^3.s$
cfm/1000 cu ft	X 0.016 67 ➤ ◄ 60 X	$L/m^3.s$*
hp/1000 cu ft	X 26.34 ➤ ◄ 0.037 97 X	W/m^3
lb/acre/day	X 1.121 ➤ ◄ 0.892 2 X	kg/ha.d*
lb/day	X 0.453 6 ➤ ◄ 2.205 X	kg/d*
cu ft/capita	X 28.32 ➤ ◄ 0.035 31 X	L/person
lb/yr/sq ft	X 4.883 ➤ ◄ 0.204 8 X	kg/m .y*
sq ft/cap	X 0.092 90 ➤ ◄ 10.76 X	m^2/person
lb/hr/sq ft	X 28.32 ➤ ◄ 0.035 31 X	$kg/m^2.h$*
lb/hr/sq ft	X 1.356 ➤ ◄ 0.737 3 X	$g/m^2.s$
cu ft/hr/ sq ft	X 0.304 8 ➤ ◄ 3.281 X	$m^3/m^2.h$*

IMPERIAL UNIT	MULTIPLIER	SI UNIT
cu ft/hr/ sq ft	X 0.084 63 ──➤ ◄──11.82 X	$L/m^2.s$*
gpm/sq ft	X 0.679 02 ──➤ ◄──1.473 X	$L/m^\lambda.s$*
lb/lb	X 10 ──➤ ◄──10 X	g/kg
gpm/lin ft	X 0.207 0 ──➤ ◄──4.832 X	$L/m.s$*
Btu/lb	X 2.326 ──➤ ◄──0.430 0 X	kJ/kg
lb/hr	X 0.126 0 ──➤ ◄──7.937 X	g/s
lb/hr	X 0.453 6 ──➤ ◄──2.205 X	kg/h*

* Not strictly SI

GEOMETRY

Areas

(1)   Triangle
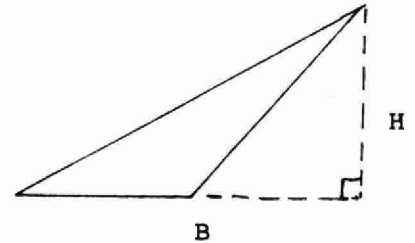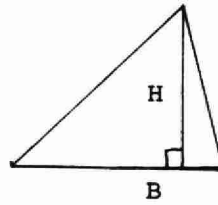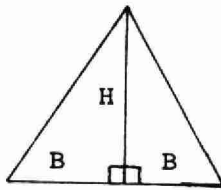
The area of a triangle:

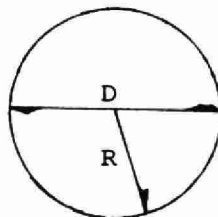$$A = 1/2 \text{ base x height}$$
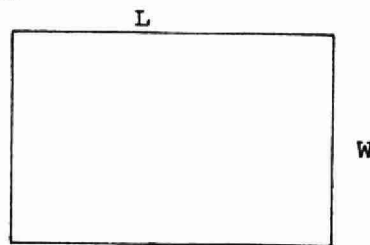
$$= 1/2 \ B \times H$$

(2)   Rectangle

The area of a rectangle:

$$A = L \times W$$

(3)   Circle

D = diameter
R = radius = 1/2 D
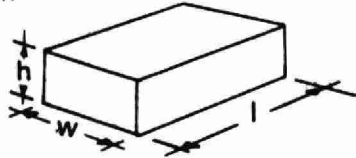C = circumference
  = 3.14

The area of a circle:

$$A = \pi R^2 \quad \text{or} \quad \frac{\pi D^2}{4}$$
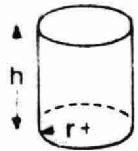
GEOMETRY

Volumes

Rectangle

Volume = l x w x h

Cylinder

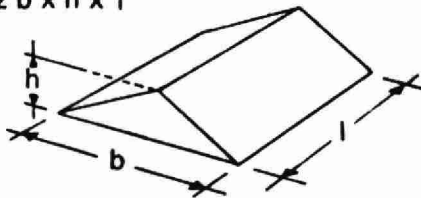Volume = $\pi r^2 h$

(area of base x height)

Triangle

Volume = 1/2 b x h x l

Cone

Volume = $\frac{\pi}{3} r^2 h$

(1/3 area of base x height)

Pyramid

Volume = 1/3 b x h x w
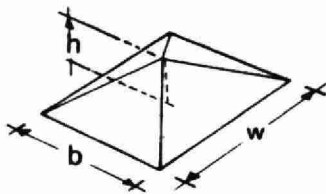
Sphere
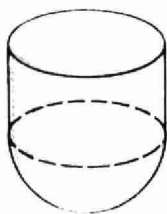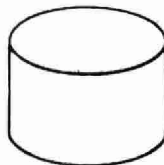
Volume = 4/3 πr^3
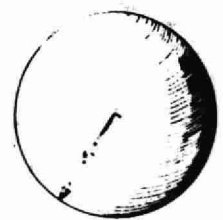
Occasionally it is necessary to calculate the volume of a tank that consists of two distinct shapes. In other words, there is no "representative surface area" for the entire shape. In this case, the volumes should be calculated separately, then the two volumes added. The diagrams below illustrate this method.

ROUND BOTTOM TANK   CYLINDER   HALF-SPHERE

77

APPENDIX 3

GUIDE TO THE USE OF SI

1. In writing the symbols in SI, Roman (upright) type, usually lower case, is used for symbols of units. If the symbol is derived from a proper name, capital Roman type is used. Symbols are not followed by a period and are not changed in the plural.

2. Units that are internationally recognized and used should not be lightly discarded even though the unit in question is not an SI unit or a preferred multiple of an SI unit.

3. Multiples and submultiples involving the factor 1 000 should be used if practical.

4. The product of two or more units is preferably indicted by a dot. The dot may be dispensed with when there is no risk of confusion with another unit symbol. For example, moment of a force: N.m, Nm.

5. The division of two units is shown in the following example.

$$\text{velocity} = m/s, \quad \frac{m}{s}, \quad m.s^{-1}$$

6. The solidus (/) must not be repeated on the same line; in the example of acceleration, m/s or $m.s^{-1}$, but not $m/s/s$.

7. In writing numbers having four or more digits, the digits should be placed in groups of three separated by a space counting both to the left and to the right of the decimal point. In the case of a four digit number the spacing is optional. For example:

1,532 is written 1 532 or 1532
132,541,816 is written 132 541 816
983,769.81678 is written 983 769.816 78

8. Prefixes should not be used in the denominator of compound units except for the kilogram (kg), which is a base unit of SI.

9. Prefix symbols are printed in Roman type without spacing between the prefix symbol and the unit symbol.

10. Double prefixes should nto be used. for example, use GW (gigawatt), not kMW.

11. An exponent attached to a symbol containing a prefix indicates that the multiple or submultiple of the unit is raised to the power expressed by the exponent. For example:

$$1 \text{ cm}^3 = (10^{-2} \text{ m})^3 = 10^{-6} \text{ m}^3$$
$$1 \text{ cm}^{-1} = (10^{-2} \text{ m})^{-1} = 10^{2} \text{ m}^{-1}$$

12. When writing the symbols of a unit, the time symbol is preferably placed last. For example, use $m^3/ha.s$ and not $m^3/s.ha$.

13. In rounding numbers by dropping the digits that are not significant, if the digit 6, 7, 8, or 9 is dropped, then the preceding digit is increased by one unit; if, on the other hand, the digit 0, 1, 2, 3, or 4 is dropped, the preceding digit is not altered. if the digit 5 is dropped, the preceding digit is rounded to the nearest even number.

14. Throughout this text the unit of length is spelled metre, in confirmity with NBS recommendations.

APPENDIX 4

ANSWERS TO PROBLEMS

SECTION B

S.I.	(IMPERIAL)
1. 72 m²	775 sq. ft.
2. 201 m²	2163 sq. ft.
3. 144 m³	5085 cu. ft.
4. 577 m³	20377 cu ft.
5. .66 m³ or 660 L	174 gals.
6. 1.2 L/s, 103.7 m³/d	27397 gals.
7. 1.5 m³	396 gals.
8. 25 d, 6 h	
9. 5.7 h or 5 h 42 min	
10. 90 kg	198 Lbs.
11. 5.1 mg/L or 1.9 kgCl	5.1 ppm or 4.2 lbs.

12.

1 kg	2 kg	4 kg	10 kg	500 g
4 kg	8 kg	16 kg	40 kg	2 kg
20 kg	40 kg	80 kg	200 kg	10 kg
500 g	1 kg	2 kg	5 kg	250 g
200 mg	400 mg	800 mg	2 g	100 mg

13.

1	2	5	20	0.4	
0.2	0.4	1	4	0.08	All Figures
0.1	0.2	0.5	2	0.04	expressed
5	10	25	100	2	mg/L

14. a) 86.6%   b) 3.4%

15. 540 kg   1191 lbs.

16. 25 kg, 25 L   55 lbs or 6.6 gals

Extra Problems   (IMPERIAL)

1.   4 m^3 141 cu. ft.
2.   3.5 m^3/d   925 gals
3.   630 kg H$_2$O   1389 lbs.
     225 kg C   496 lbs.
     45 kg Al$_2$SO$_4$ 99 lbs
4.   22.5 m^3 or 22 500 L   795 cu. ft. 4961 gals
5.   864 kg   1905 lbs
6.   2 mg/L   2 ppm
7.   19.4 kg of sol'n   5 gals

SECTION C

1.   140 m^2 1506 sq. ft.
2.   153 m^2 1646 sq. ft.
3.   48 m^3 12681 gals.
4.   1 021 m^3 269748 gals
5.   1.1 L/s, 95 m^3/d   17 gpm, 25099 gpod
6.   1 800 L or 1.8 m^3/d   475 gals.
7.   25 d
8.   1.56 m^3/s, 1 560 L/s   2469 gpm
9.   6 h (4 fills a day)

10.

    1 kg   2 kg   4 kg   10 kg   500 g
    4 kg   8 kg   16 kg   40 kg   2 kg
   20 kg   40 kg   80 kg   200 kg   10 kg
  500 g   1 kg   2 kg   5 kg   250 g
  200 mg   400 mg   800 mg   2 g   100 g

11.

1   2   5   20   0.4
0.2   0.4   1   4   0.08   All figures
0.1   0.2   0.5   2   0.04   expressed
5   10   25   100   2   in mg/L

12.   90 kg Cl$_2$ 198 lbs.

13.   1.9 kg Cl$_2$/d, 0.7 mg/L   4.2 lbs.   0.7 ppm

81

EXTRA PROBLEMS

1. 357 m^3 94319 gals.
2. a) 133.3 L/s   2113 gpm
    b) 11 520 m^3/d   3 mgd
3. No; the calculated
    flow is 1 036.8 m^3/d   0.27 mgd
4. 8.4 kg Cl$_2$/d   18.5 lbs.
5. a) 40%
    b) 94%

SECTION E   (IMPERIAL)

1. 3 000 mg/L   3000 ppm
2. 540 kg BOD$_5$ 1190 lbs.
3. 0.5
4. 5 mg O$_2$/h/g
5. 38.34 m^3 8454 gals
6. MLSS 2 364 mg/L
    SVl 88.8
7. SS Concentration 4.8 mg/L
8. 6 810 kg   15013 lbs
9. 2 730 kg   6018 lbs.
10. 3 155 kg   6954 lbs.
11. 3.9 d

SECTION G

1. 0.108
2. 607 kg   1388 lbs.
3. 64.7% reduction
4. 3.05 kg/m^3/d   0.19 lbs/ft^3/day
5. 1.5 kg/m^3/d   0.09 lbs/ft^3/day
6. 0.6 m^3/kg   9.6 ft /lb
7. i)   16 d
    ii)   2.5 kg/m^3/d   0.16 lbs/ft^3/day
    iii) 48.8%
    iv)   0.45 m^3/kg   7.2 ft^{3}lb

SECTION I   (IMPERIAL)

1. 1.36 L/M².S   16 ft /h/ft
2. 45.5 m/h
3. 10.3 L/m².s
4. 4 L/m².s

SECTION K

1. 1.66 mL
2. 1.55 mL
3. 5 425 mL/min or 90.4 mL/s
4. Alum 53 mL/min
    Activated Silica 381.9 mL/min
5. 943 mL/min
    1 357.9 L/d   (359 gals)
6. 162 kg/d   (357 lbs.)